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The Influence of Participation in Socially Engaging or Complex Physical Activities on Executive Function Among Older Adults

Lyndsie M. Koon

UNIVERSITY OF NORTHERN COLORADO

Greeley, Colorado

The Graduate School

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Lyndsie Marie Koon

College of Natural and Health Sciences
School of Sport and Exercise Science
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Accepted by the Doctoral Committee

Robert Brustad, Ph.D., Co-Research Advisor

Megan Babkes Stellino, Ed.D., Co-Research Advisor

Eric Peterson, Ph.D., Committee Member

Rena Kirkland, Ph.D., Committee Member

Marilyn Welsh, Ph.D., Faculty Representative

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Accepted by the Graduate School

Linda L. Black, Ed.D.
Associate Provost and Dean
Graduate School and International Admissions

ABSTRACT

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The preservation of cognitive function is of particular importance for the maintenance of independence and functional autonomy for older adults (Hertzog, Kramer, Wilson, & Lindenberger, 2008). Physical activity is a behavioral intervention that contributes to mental and physical health; it has also been found to promote cognitive function across a lifespan. Cognitive processes that assist with goal-directed behavior to successfully complete everyday tasks known as executive functions are susceptible to physical activity participation especially among youth, adolescent, and older adult populations. Various aspects of the physical activity context might help mediate improvements to executive function including the task complexity of the physical activity and the level of social engagement that might occur during the activity.

The purpose of the current study was to explore the relationship among the level of task complexity, the level of social engagement during physical activity, and the variability in executive functioning for physically active older adults. Participants (N = 75, 60% females, 60-73 years of age) reported various types of physical activity involvement over a typical week. The activities were evaluated separately for the level of task complexity and the level of social engagement associated with the physical activities. Three components of executive function were measured: inhibition as assessed by a computerized flanker test; Trail Making Test: Parts A and B to evaluate cognitive flexibility; and the forward, backward, and sequencing digit span tasks to assess working memory. Demographic variables were evaluated and included gender, age (*M*age = 64.43 years), completed level of education (*M* = 16 years), additional number of household members (*M* = 2) and physical fitness level (*M*females = 99.16 beats per minute and *M*males = 89.28 beats per minute). The Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) was administered and participants all scored 25 out of 30 possible points or higher (*M*score = 29); therefore, no one was excluded for predetermined cognitive decline based on the results of this test.

Correlational analyses revealed significant moderate, positive relationships among the three predictor variables and between social engagement and age and task complexity and age. Preliminary analyses indicated non-significant relationships among the demographic variable and the outcome variables. Multivariate multiple regressions were calculated to examine the variability in executive function according to the level of social engagement and task complexity of the physical activities most frequently participated in as reported by the participants. Results indicated higher levels of social engagement and more complex physical activity tasks for this sample of older adults did not contribute to variability in any index of executive function. For this sample, other variables might have more saliently influenced executive functioning. To date, this was the first study to directly evaluate the level of social engagement and task complexity for various types of physical activities. Further research is needed to control for these aspects of physical activity contexts and directly evaluate their influence on executive functioning among older adult populations. Future studies could assist practitioners with the design of a

physical activity intervention for older adult that would most effectively influence executive function.

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CHAPTER I

INTRODUCTION

Adults over the age of 65 made up nearly 13% of the U.S. population in 2000 and this age group is projected to grow to nearly 19% by 2030 (Federal Interagency Forum on Aging-Related Statistics, 2012; World Health Organization, 2016). With this trend toward increased longevity, quality of life issues for this growing population are of major concern. Thus, much of the motivation underlying research in gerontology involves examining how various behavioral interventions intended to improve physical, mental, and emotional health for older adults, impact functional independence, and promote successful aging (Hertzog, Kramer, Wilson, & Lindenberger, 2008). Physical activity is known to contribute to the maintenance and enhancement of a variety of favorable physical and mental health outcomes including the reduction of cardiovascular disease, increased mobility and physical capabilities, reduced adult onset diabetes, and a reduction in certain cancers and depression (Bouchard & Despres, 1995). Furthermore, physical activity participation has been linked to preserving cognitive function and even reversing signs of age-related cognitive decline among older adults (see Colcombe, Kramer, McAuley, Erickson, & Scalf, 2004; McAuley, Kramer, & Colcombe, 2004 for reviews).

Physical activity (PA) is defined as any bodily movement that results in energy expenditure (Caspersen, Powell, & Christenson, 1985), and encompasses exercise and sport activities. Exercise is considered to be a subset of PA, which is defined as planned, structured, and repetitive bodily movements with an objective to improve or maintain some component of fitness (Caspersen et al., 1985). Sport is defined as an officially governed, competitive physical activity where participants are motivated by internal and external rewards (Coakley, 2014). For the purposes of this study, the term *physical activity* was used, although various sport and exercise activities were included in the data collection process and described as physical activities.

Physical activity involvement serves as a non-pharmaceutical behavioral intervention approach that positively influences both physical and mental health for aging adults. Physical activity participation has been found to positively alter brain structure and function (Colcombe et al., 2004, 2006), protects against dementia (Larson et al., 2006), and enhances performance on a variety of cognitive tasks, particularly ones that require executive function (EF; Cassilhas et al., 2007; Colcombe et al., 2004; Kramer et al., 1999; Lachman, Neupert, Bertrand, & Jette, 2006; Lautenschlager et al., 2008; Liu-Ambrose et al., 2010; Voss et al., 2010). Executive functions (EFs) are processes that help regulate goal-directed behavior through effortful thinking and reasoning (Diamond, 2013; Lunt et al., 2012) and assist with everyday tasks such as planning, problem solving, driving, or learning a novel skill (Bixby et al., 2007; Martyr & Clare, 2012). Specific components of EFs include working memory, which is defined as the ability to temporarily store and utilize information (Baddeley & Hitch, 1974). A deficit in working memory might affect an individual's ability to remember or comprehend a number of cognitive outcomes involved in reasoning (Zelinski & Lewis, 2003) or in processing complex sentences (Stine-Morrow, Soederberg Miller, Gagne, & Hertzog, 2008). Additional processes that fall under the umbrella term of EFs include inhibition and cognitive flexibility, also known as shifting. Inhibition refers to the ability to inhibit socially inappropriate actions, thoughts, or emotions and to resist the interference of distracting stimuli (Miller, 2005) while cognitive flexibility allows an individual to alternate attention between two tasks or activities with differing goals (Arbuthnott & Frank, 2000).

Age-related cognitive decline is associated with brain atrophy caused by a decrease in brain vascularization and cerebral blood flow, a decline in neurotransmitters that contribute to a slow but steady reduction in neuronal activity (Bixby et al., 2007), and reduced myelination that weakens neuronal efficiency (Princiotta, DeVries, & Goldstein, 2014). Grey and white brain matter might decrease by as much as 15-50% between the ages of 30 and 90 years and occurs predominantly within the prefrontal cortex (Royall, Palmer, Chiodo, & Polk, 2014)--the region of the brain believed to be primarily responsible for EFs. Executive function capacities improve during the early stages of life and adult level performances on tasks requiring EFs are not typically reached until young adulthood (Welsh, 2002). Due to the age-related physiological declines to the prefrontal cortex brain region, older adults might experience difficulty successfully completing everyday tasks and, thus, struggle with functional independence and autonomy (Karr, Areshenkoff, Rast, & Garcia-Barrera, 2014; Workman et al., 2000). The preservation of the functional capacity of the prefrontal cortex is of major interest for researchers due to the accelerated decline of this brain region and the role EF plays in everyday, goal-directed activities (Bixby et al., 2007; Martyr & Clare, 2012). Fortunately, research has provided empirical evidence for neuroplasticity or the strengthening of synaptic transmission (Churchill et al., 2002), suggesting the brain can be considered flexible and has an ability to reorganize neural circuitry even into older ages (Park & Gutchess, 2004; Park, Gutchess, Meade, & Stine-Morrow, 2007). Due to this neuroplasticity effect, findings from research studies indicated behavioral interventions that offer a high level of mental and/or physical stimulation through social networking, PA, or learning a novel skill could improve cognition in older adults (Hertzog et al., 2008). According to Fratiglioni, Paillard-Borg, and Winblad (2004), three lifestyle factors positively influence the rate of cognitive decline: socially integrated networks, cognitive-based leisure activities, and regular PA. These environmentally enriched conditions provide opportunities for mental stimulation resulting in synaptogenesis, or the formation of new synapses in the brain, along with neurogenesis (growth of new neurons) and angiogenesis, which refers to the growth of new capillaries (Churchill et al., 2002). Results from empirical research indicated frequent engagement in social, physical, and/or cognitively challenging activities served as a significant predictor of cognitive function later in life and had a positive impact on cognitive performance (see Hertzog et al., 2009 for a review).

Previous experimental studies and meta-analyses that examined the impact of PA on EF found aerobic training specifically was effective at not only improving cardiovascular fitness but also in altering brain structure and function among older adults (Colcombe et al., 2004; Kramer et al., 1999; Scherder et al., 2014). However, other aspects of aging, such as associated decreases in cardiovascular fitness capacity or mobility, might limit aerobic activity for seniors. Researchers (Cassilhas et al., 2007; Liu-Ambrose et al., 2010) found resistance training to positively impact brain structure and function and this form of PA can be performed even when mobility and cardiovascular fitness levels are limited. Furthermore, resistance training might increase muscle mass and strength, leading to a reduced likelihood of falls and physical disability (Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012). Other meta-analyses suggested the effects of PA interventions on cognitive function were greatest when they combined aerobic and resistance training (Colcombe & Kramer, 2003; Kelly et al., 2014; Smith et al., 2010), which has led researchers to further examine the selective effects these two types of PA have on brain structure and executive functioning. Other types of PA that have been examined include water aerobics (Hawkins, Kramer, & Capaldi, 1992), balance and stability activities (Liu-Ambrose et al., 2010), Tai-chi (Mortimer et al., 2012; Nguyen & Kruse, 2012; Taylor-Piliae, Silva, & Sheremeta, 2010), and yoga (Gothe, Kramer, & McAuley, 2014). Results revealed positive changes to EFs and other cognitive processes following involvement in these various types of PA. Other PA variables were empirically examined and included activity intensity (Chen, Yan, Yin, Pan, & Chang, 2014) and the frequency and duration (Davis et al., 2007, 2011) of the PA. Inconsistent intervention designs provided little replication between the methods utilized, resulting in inconclusive findings. Additional PA variables have recently been proposed as potential mediating variables and include opportunities for social engagement (SE) during the activity and the degree of task complexity (TC) associated with the PA among youth and adolescent populations (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008; Chang, Tsai, Chen, & Hung, 2013; Crova et al., 2014; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009). However, research has not yet systematically addressed the mediating influence of TC and SE during PA on EF in older adults.

Need for the Study

It has recently been proposed that TC and SE might mediate the relationship between PA and improve cognitive function (Tomporowski, McCullick, Pendleton, & Pesce, 2015). The level of TC refers to the degree to which the PA participant has to engage mentally and/or perform complex motor movements to complete the task at hand. For example, PA interventions designed to incorporate a high level of TC might involve complex, multi-limb coordinative skills or object manipulation such as serving a tennis ball or manipulating a resistance band. Other examples of complex physical activities might require participants to learn a novel skill or movement or exert concentrated mental engagement through rapid decision-making while adapting to changes within the PA condition such as group game settings (Best, 2010; Budde et al., 2008; Crova et al., 2014). Tomporowski et al. (2015) suggested interventions that included components of high TC provided greater mental stimulation when compared to stable, simple, and repetitive physical activities. Research results indicated complex physical activity with high motoric and/or high cognitive demands elicited greater improvement in cognitive performance (Budde et al., 2008; Chang et al., 2013; Crova et al., 2014; Pesce et al., 2009) and benefited brain structure and function (Castelli, Hillman, Hirsch, Hirsch, & Drollette, 2011) when compared with control conditions involving simple physical activities (i.e., walking on a treadmill). Researchers have hypothesized that older adults participating in complex physical activities that are externally-paced or unpredictable, such as tennis or table tennis, will display greater improvements to cognitive functioning than older adults who participate in less complex activities that are internally-paced, such as swimming laps or walking on treadmills (Dai, Chang, Huang, & Hung, 2013). Other researchers hypothesized that physical activities considered multicomponent, such as the combination of aerobic and strength training, would positively impact neuroplasticity to a greater extent, thus preserving or improving cognitive function when compared to single component physical activities (Forte et al., 2013).

It was also suggested that more opportunities for SE during physical activities for children would result in greater cognitive gains than physical activities performed individually (Castelli et al., 2011; Crova et al., 2014; Pesce et al., 2013). In studies involving youth samples, higher levels of SE during PA resulted in enhanced cognitive performance (Crova et al., 2014; Pesce et al., 2013) and improved brain structure (Castelli et al., 2011) to a greater degree than physical activities performed alone. Dai and colleagues (2013) suggested the SE opportunities provided during participation in tennis and table tennis contributed to the superior cognitive performance of older adults compared to the individual treadmill or swimming PA group.

More extensive social networks have been associated with higher levels of EF (Seeman, Lusignolo, Albert, & Berkman, 2001) as well as slower rates of cognitive decline and higher overall cognitive function in older adults (Barnes, De Leon, Wilson, Bienias, & Evans, 2004). This might be due to the psychosocial benefits of SE, which serve as a stress reducer, result in a more positive emotional affect, and improve social competence (Fratiglioni et al., 2004). It was proposed the maintenance of cognitive function as a result of greater social networks might be due to the neural stimulation SE provides, increasing synaptogenesis, neurogenesis and angiogenesis in the brain, resulting in improved brain structure and function (Churchill et al., 2002).

Purpose of the Study

The purpose of this study was to examine the relationships among complex and socially engaging PA environments and cognitive function in older adults who participate in regular PA. The study design was cross-sectional and was intended to understand how the level of TC and SE during PA participation explained variability in EF performance in adults aged 60 to 73 years. Preliminary analyses examined the level of SE and TC related to each PA reported by the participants. Further analyses explored the relationship among lifestyle factors such as physical fitness levels, completed level of education, and additional number of household members in relation to the outcome variables. Main analyses were conducted to determine the degree to which the level of TC and the level of SE during PA explained variability in performance on cognitive tasks that required various aspects of EF.

Research Questions

Q1 Does frequent participation in physical activities that involves a high level of SE explain variability in performance on executive functioning tasks?

Q2 Does frequent participation in physical activities that involves a high level of TC explain variability in in performance on executive functioning tasks?

Q3 Does frequent participation in physical activities that involves *both* a high level of TC and a high level of SE explain variability in performance on executive functioning tasks?

Based on researchers' suggestions (Crova et al., 2014; Dai et al., 2013; Tomporowski et al., 2015), it was anticipated that individuals who engaged in complex PA environments (i.e., group games or fitness classes where there were objects to manipulate) would perform significantly better on EF tasks when compared to individuals who engaged in less complex PA modes (i.e., swimming laps or walking on a treadmill). Similarly, it was anticipated individuals who participated in PA settings that required higher levels of SE (e.g., basketball, doubles tennis) or provided greater opportunity for SE during participation (e.g., group fitness class) would perform significantly better on EF tasks than individuals who engaged in physical activities individually. The influence of TC and SE was also examined in combination with the frequency of participation in the reported activities to determine their combined influence on the outcome measures. It was anticipated individuals who engaged in both highly complex and highly social PA settings would perform better on tasks requiring EF when compared with individuals who less frequently engaged in PA contexts that were both socially engaging and complex.

Significance of This Study

The goal of this study was to determine characteristics within the PA environment that might explain variability in cognitive function in older adults. Various components of PA were examined to determine the influence of PA variables such as intensity and duration on cognitive change. This study was designed to examine the potential influence of TC and SE during PA on executive functioning among older adults. Results from research with rodent and youth samples revealed positive changes to brain structure and function following PA interventions but to date, no studies have systematically examined the role of TC and SE in PA settings with older adult populations. The findings from this study might be beneficial to the specific design of future PA interventions for older adult populations.

Limitations of the Study

The primary limitation was the cross-sectional design utilized for this study as data were only collected at one point in time. Consequently, the results could not be interpreted as causal despite associations observed in the results. Unlike an experimental study where results could be attributed to the treatment, causality could not be inferred from a cross-section (Mann, 2003). Specific to the current study, it was assumed many other variables influenced both PA preference and the current EF performance among these participants. Such variables might have included genetics and lifestyle factors such as gender, socioeconomic status, and ethnicity, as well as behavioral factors such as tobacco or alcohol consumption and nutrition practices (Hertzog et al., 2008).

Definition of Terms

The following terms are discussed throughout this dissertation. Each term is discussed and defined more extensively in Chapter II.

Cognition--The ability to reason quickly and abstractly, direct attention, and problem solve (Biddle & Asare, 2011).

Executive function (EF)--Higher order, effortful top-down cognitive processes that "allow an individual to perceive stimuli from his or her environment, respond adaptively, flexibly change direction, anticipate future goals, consider consequences, and respond in an integrated or commonsense way" (Baron, 2004, p. 135). Executive functions "reflect the ability to manage and regulate one's behavior in order to achieve desired goals" (Clark et al., 2012, Discussion, para. 3). Executive functions are "a collection of processes that are responsible for guiding, directing, and managing cognitive, emotional, and behavioral functions, particularly during active, novel problem solving" (Gioia, Isquith, Guy, & Kenworthy, 2000, p. 1).

- Inhibition--The ability to inhibit a prepotent response and the ability to reject distraction by irrelevant stimuli (Miller, 2005).
- Cognitive flexibility/shifting--The ability to alternate attention between two tasks or activities with differing goals (Arbuthnott & Frank, 2000).
- Working memory--The ability to actively maintain and manipulate information (Shah & Miyake, 1999).

Neuroplasticity--The strengthening of synaptic transmissions within the brain (Churchill et al., 2002).

Physical activity--Any bodily movement that results in energy expenditure (Caspersen et al., 1985). As previously stated, for the purposes of this study, the term *physical activity* was used exclusively, although various modes of exercise and sport were included in the data collection and described as physical activities.

- Exercise--A subset of PA defined as planned, structured, and repetitive bodily movements with an objective to improve or maintain some component of fitness (Caspersen et al., 1985).
- Sport--Well-established, officially governed, competitive physical activities in which participants are motivated by internal and external rewards (Coakley, 2014).

CHAPTER II

REVIEW OF LITERATURE

Participation in PA has long been associated with improved physical, emotional, and mental health. Physical activity plays a role in reducing the risk of cardiovascular disease, obesity, diabetes onset, and osteoarthritis (Dishman, Washburn, & Heath, 2004) and serves as an antidepressant and anxiety reducer by releasing hormones and neurotransmitters to produce a calming effect and induce positive affect (Churchill et al., 2002; Taras, 2005). Involvement in both acute and chronic PA has resulted in structural and functional changes to the brain, which subsequently improve performance on tasks that require various cognitive processes, particularly among children, adolescents (Sibley & Etnier, 2003), and adults over the age of 55 years (Colcombe & Kramer, 2003). It has been proposed that PA might induce optimal brain development in young people and contribute to cognitive benefits associated with PA participation for this population (Hillman, Castelli, & Buck, 2005; Hillman, Erickson, & Kramer, 2008). Among older adults, PA has been found to increase vascularization in certain brain regions, which reduces the risk of dementia and Alzheimer's disease (AD; Churchill, et al., 2002; Fratiglioni et al., 2004). Therefore, PA might serve as an important contribution to successful aging as represented by physical and mental health and overall functional autonomy (Colcombe & Kramer, 2003; Etnier et al., 1997).

Empirical research on the specific aspects of PA participation that affect cognitive function across all populations has grown substantially in the past decade (Scherder et al., 2014). Although some results from previous research studies utilizing cross-sectional research designs have indicated positive relationships among fitness levels, PA participation, and cognitive function, findings from randomized controlled trial studies have not always revealed consistent, positive results. Researchers often explained these discrepancies in terms of various methodologies utilized. Physical activity intensity, type, frequency, and duration varied among PA intervention designs with little replication across studies. Additionally, the assessment of changes to cognition differed in relation to the specific cognitive process assessed following a PA intervention (see Colcombe & Kramer, 2003; Etnier, Nowell, Landers, & Sibley, 2006; Hillman et al., 2008; Kramer & Erickson, 2007; Sibley & Etnier, 2003 for reviews). Researchers recently found higher order, top-down processes known as EFs were particularly sensitivity to PA interventions among both youth and adult populations (Colcombe & Kramer, 2003; Etnier & Chang, 2009; Dahlin, Nyberg, Backman, & Neely, 2008; Tomporowksi, Davis, Miller, & Naglieri, 2008). Executive functions require more effortful processing than automatic, lower level cognitive functions such as reaction time and help regulate goal-directed behavior by allowing for effortful thinking and reasoning (Diamond, 2013; Lunt et al., 2012). Study results showed support for better executive functioning among participants with higher levels of fitness (Colcombe et al., 2004, 2006) and following acute and chronic PA interventions (Crova et al., 2014; Forte et al., 2013) across a lifespan.

A current goal of researchers is to identify the types of PA interventions that enhance cognitive function, particularly executive functioning in various populations.

This literature review includes an in-depth discussion of findings from studies that had examined the relationship between PA and cognitive function with a specific focus on EFs as outcome variables across all populations. Results from research studies using cross-sectional designs are subsequently reviewed to describe the relationships among physical fitness levels, PA participation, and EF. Experimental designs are discussed in terms of the specific PA intervention that was implemented and the associated cognitive outcomes. Potential mediating variables are also reviewed in detail with a specific focus on the impact of TC and SE during PA on changes to EFs across all populations.

Cognition and Physical Activity

Cognition has been defined as the ability to reason quickly and abstractly, to direct attention, and to problem solve (Biddle & Asare, 2011). The investigation of cognitive functions involves examination of both automatic (i.e., response time) and effortful mental processes known as EFs (i.e., strategic planning, problem solving; Ellis & Hunt, 1993). Cognitive effects have been assessed through IQ scores, academic achievement levels, automatic processing speed and accuracy, perceptual skills, memory, and EFs. The following sections review executive functioning in relation to PA participation across all populations.

Executive Function

Executive functions are higher order cognitive processes that allow an individual to engage in a multitude of complex tasks such as learning a novel skill, multi-tasking, problem solving, and scheduling or planning (Bixby et al., 2007; Princiotta et al., 2014). Core EFs include cognitive flexibility, working memory, and inhibition. Cognitive flexibility, also known as shifting, is the ability to alternate attention between two tasks or activities with differing goals (Arbuthnott & Frank, 2000). Working memory refers to an individual's ability to actively maintain, manipulate and utilize information (Shah & Miyake, 1999). Inhibition refers to the ability to inhibit socially inappropriate actions, thoughts or emotions, and resist the interference of distracting stimuli (Miller, 2005).

Results from previous studies among youth populations indicated higher levels of EF are directly related to performance in academic subjects including reading, writing, and math (Diamond, 2002) in addition to overall school success (Gathercole, Pickering, Knight, & Stegmann, 2004), school readiness (Blair & Razza, 2007), and classroom behavior (Jahromi & Stifter, 2008). Higher levels of EF in youth are also associated with the development of social and emotional skills (Best, 2010). Poor EF, often referred to as executive dysfunction, has been related to clinical disorders such as ADHD or spectrums of autism (Diamond, DeLuca, & Kelley, 1997), learning disabilities (e.g., dyslexia) and disruptive classroom behavior (Cole, Usher, & Cargo, 1993).

The core components of EFs (cognitive flexibility, working memory, and inhibition) develop at varying rates. Improvements to EF in children are believed to be associated with the slowly maturing frontal brain regions (Stuss, 1992). Adult-level performance on EF tasks is typically reached in late childhood or early adolescence (Welsh, 2002). Hillman et al. (2008) noted PA participation might optimize this cortical development as gray matter increases substantially from infancy through early childhood. These researchers suggested the youth brain is more responsive to neural stimulation provided through PA participation, which might promote positive brain function later in life (Hillman et al., 2008).

Age-related cognitive decline among older adults has been found to directly impact an individual's ability to perform daily tasks requiring EFs such as planning and scheduling or learning a novel skill (Bixby et al., 2007; Princiotta et al., 2014). In adulthood, EFs are essential for delaying gratification, staying on task, and the development of social skills. These capabilities have been associated with a higher probability of career satisfaction, marital harmony, better social relationships, and higher overall quality of life (Diamond, 2013). The specific deterioration of executive processes results in slower processing speed, difficulty multitasking or switching between tasks, as well as an inability to retain information and utilize it to carry out a mental task (Huizinga, Dolan, & van der Moden, 2006; Princiotta, et al., 2014).

Participation in PA has been found to reduce the risk of cognitive decline by 38% (Sofi et al., 2011), reduce the risk of dementia by 28%, and reduce the risk of Alzheimer's disease by 45% (Hamer & Chida, 2009). Results from neuroimaging studies have indicated changes to the structure of the brain among older adults who participated in PA. These changes included a reduction in brain atrophy, particularly in the prefrontal and temporal regions (Colcombe et al., 2003; Gordon et al., 2008) and the hippocampus (Erickson et al., 2009). Gerontology researchers have focused on testing interventions aimed at preserving cognitive function and, therefore, improving quality of life factors for this population (Bixby et al., 2007; Hertzog et al., 2008; Karr et al., 2014). Colcombe and Kramer (2003) evaluated various hypotheses used to explain changes in cognitive performance among adults 55 years and older following PA interventions. Results showed tasks requiring EF processes improved significantly more so than tasks requiring automatic, visuospatial, or controlled processes. The researchers suggested EFs are likely most susceptible to improvements following chronic PA participation. Collectively, these findings indicated the necessity to explore the impact of PA on EF outcomes across all populations, particularly youth and older adults.

Physical Activity and Executive Function

The following section discusses the findings from studies that explored the impact of PA on EFs across the lifespan and include both cross-sectional and experimental study designs. Specific aspects of the PA interventions are highlighted as well as the outcomes related to executive processes. Additionally, the researchers' conclusions explaining *how* and *why* particular PA interventions successfully induced changes to EFs in all populations are addressed.

Youth Populations

Findings from an early cross-sectional study by Hillman et al. (2005) revealed a positive relationship between youth participants with higher levels of physical fitness and better performance on attentional tasks, working memory tasks, and faster response latencies compared to their less fit peers. Buck, Hillman, and Castelli (2008) also reported higher levels of aerobic fitness were associated with better performance on both congruent and incongruent trials of the Stroop color-word task assessing cognitive flexibility and inhibition among 7- to 12-year-old children. Pontifex et al. (2011) found higher-fit children performed better on inhibition tasks, which was assessed by evaluating event-related potentials (ERPs) during the Eriksen flanker task (Eriksen & Eriksen, 1974) compared to less fit children. Event-related potentials are a neuroelectical indicator of stimulus encoding, attention allocation, efficiency of stimulus classification, and response execution within a given task (Kamijo et al., 2011). Pontifex and colleagues found a larger P3 amplitude in the higher fit participants, indicating a greater capacity to flexibly allocate attentional resources, utilize cognitive flexibility, and inhibit responses. The P3 amplitude is a neuroelectrical process typically assessed using ERPs during performance on various cognitive tasks. Results from an additional cross-sectional study indicated higher fit children had greater bilateral hippocampal volume and performed better on memory tasks than lower-fit children (Chaddock et al., 2010).

Van der Niet, Hartman, Smith, and Visscher (2014) analyzed the mediating role executive functioning played in the relationship between academic achievement and physical fitness levels among children aged 7- to 12-years-old. Using a structural equation modeling technique, findings revealed significant relationships between physical fitness and executive functioning and a significant relationship between executive functioning and academic achievement. A significant indirect relationship between fitness levels and academic achievement was also found through executive functioning. The researchers suggested EF served as the mediating variable in the relationship between physical fitness levels and academic achievement.

Researchers also explored the impact of acute and chronic PA interventions on executive functioning in youth and adolescent populations. Verburgh, Königs, Scherder, and Oosterlaan (2013) conducted a meta-analysis, which included 24 studies that assessed changes in EF among children (6-12 years), adolescents (13-17 years), and young adults (18-30 years) following acute (n = 19) or chronic (n = 5) PA interventions. The studies utilized randomized control trial research designs for both acute and chronic interventions and assessed changes to inhibition (n = 13), working memory (n = 5), planning (n = 4), and cognitive flexibility or shifting (n = 5) following the PA intervention. The acute PA interventions were found to produce the greatest change to performance on tasks requiring inhibition. Results revealed moderate effects for the preadolescent (*d* = 0.57) and in the adolescent (*d* = 0.52) samples, and a small-to-moderate effect for the young adult sample (*d* = 0.42). The researchers noted the acute PA interventions had similar effects on inhibition across the three age groups and it was concluded acute PA could positively impact this aspect of EF regardless of development. A clear limitation was the majority of the acute PA studies assessed changes to inhibition and consequently the effect sizes for other EFs examined were based on a small number of studies. It was concluded the positive impact of acute PA on inhibition was promising as this particular aspect of EF is essential for youth, adolescents, and young adults to regulate behavior and emotions in a variety of contexts. Of the five studies that assessed changes to cognition following chronic PA interventions, three studies examined performance on tasks requiring planning, while another study explored changes to performance on tasks requiring working memory, and the final study evaluated changes to performance on inhibition tasks. Preadolescent children were participants for four of the chronic PA studies while the fifth study used young adult participants. Results revealed a non-significant effect size overall (*d* = 0.14) from studies utilizing chronic PA interventions across all age groups. The researchers proposed these results were due to the small number of studies assessing chronic PA interventions on the EF outcome variable. Other limitations noted by the researchers were the variations of duration and intensity among both the acute and chronic PA interventions. The duration of the acute PA intervention ranged from 10 to 40 minutes across the three age groups while the duration of the chronic interventions ranged from 900 to 21,600 minutes, presenting a lack of consistency in the design of the interventions. Regarding intensity, only 12 of the 25 studies evaluated participants' heart rate during the PA intervention. Thus, the researchers were unable to analyze the effect of intensity on changes to EF, contributing to the non-significant findings from the meta-analysis.

To examine the effect of an acute bout of PA on EFs, Chen et al. (2014) randomly assigned third and fifth-grade children to two different 30-minute PA groups of lower and higher intensities (~42% of max heart rate or ~65% of max heart rate). The participants completed inhibition, working memory, and shifting tasks before and after the PA intervention. The researchers hypothesized the acute bouts of PA would positively impact all components of EF in both PA groups compared to a control group that did not participate in PA. Results revealed significant improvements to the fifth graders' inhibition and working memory performance to a greater extent than the third graders but this group did not improve shifting performance significantly. These findings indicated the selective effect of PA on the different aspects of EF during these developmental years. These results supported previous findings that inhibition is the first EF to develop, followed by working memory, and then shifting (Brocki & Bohlin, 2004). Chen and colleagues also suggested the PA contexts of group games had high ecological validity when compared to previous study designs that utilized laboratory settings (treadmills and cycle ergometers) to explore the impact of acute PA on EF in children (Lambourne & Tomporowski, 2010). They noted the group activity context offered opportunities for social interaction and was cognitively demanding as the participants had to adjust their speed and distance relative to other participants in the group. The positive changes to EF following the group game activities in this study supported Pesce (2012) and

Tomopowoski and colleagues' (2015) suggestions that researchers should shift their focus away from the intensity, frequency, and duration of PA contexts and instead focus on the cognitive demands and social interaction opportunities provided to youth participants during PA.

Results from studies utilizing chronic PA interventions also revealed improvements to EF among youth populations. Davis and colleagues (2007, 2011) implemented a PA intervention over three months among children between the ages of 7 and 11 years who were classified as sedentary and overweight. The researchers randomly assigned the participants to one of three treatment groups: a control group with no PA, a daily 20-minute aerobic games group, or a daily 40-minute aerobic games group. The control group participated in board and card games while the participants in the aerobic games groups played running games, modified basketball and soccer games, and jumped rope. The instructors of the intervention emphasized intensity, enjoyment, and safety as opposed to competitiveness or skill development. The researchers assessed changes to cognition using EF tasks, achievement measures, and functional magnetic resonance images (fMRIs). Results showed significantly improved EF performance and math achievement scores as well as increased prefrontal cortex activity in both PA groups. The researchers did not find a significant difference in EF performance between the 20-minute and 40-minute PA groups and suggested daily, vigorous PA might improve EF for overweight children.

Pesce et al. (2013) explored the impact of a six-month physical education intervention on the EF of 5- to 10-year-old children (N = 250). Two types of PA interventions were implemented. The experimental group was led by a specialist physical education instructor who was instructed to develop games that emphasized variability of practice, was motorically challenging, and required the participants to utilize perceptual-motor adaptation abilities to the different games. This PA intervention was designed to challenge EFs through effortful cognitive engagement and a high level of contextual interference. The control group was led by a general physical education (PE) teacher who was not privy to the purpose of the research study and was told to implement typical physical activities. The researchers hypothesized the cognitive and coordinative demands of the experimental group would improve executive functioning to a greater extent than the PA intervention applied to the control group. Results indicated significant changes to attention among the experimental group participants compared to the control group; the researchers attributed the findings to the cognitive challenges promoted in the specialist-led PE group.

Crova et al. (2014) compared the impact of two types of PA interventions on 9- and 10-year-old children's EF performance over an eight-week period. Participants were randomly assigned to an experimental group where they engaged in an enhanced PA program or a control group that engaged in traditional physical activities. The enhanced PA program provided participants the opportunity to develop fundamental motor skills and coordinative ability through individual and team games in addition to tennis-specific training that promoted object control and bimanual coordination. The intent of the enhanced PA intervention was to expose the participants to cognitively demanding activities through externally regulated group games and learning to play tennis. The program associated with the traditional PA group was not explained in detail. After controlling for improvements to physical fitness levels in both groups, the results revealed significant improvements to inhibition performance following participation in the enhanced PA activity group. Participants in the enhanced PA group who were classified as overweight displayed more pronounced improvements to inhibition than their non-overweight peers. Crova and colleagues concluded the intervention effects were not mediated by any changes to aerobic fitness levels. Instead, the authors proposed the cognitive demands and social interaction promoted in the enhanced PA program might have influenced the improvements to EF through greater neural stimulation.

Schmidt, Jäger, Egger, Roebers, and Conzelmann (2015) assigned 10- and 12-year-old children to one of three groups: a PA group that involved high levels of physical exertion and high cognitive engagement through the use of team games; a PA group that involved high levels of physical exertion but low cognitive involvement through individualized aerobic activities; or a control group that involved low physical and cognitive involvement. The high physical exertion and high cognitive engagement group participated in learning sport-specific skills (floorball and basketball) that required the utilization of complex eye-hand coordination, effortful mental engagement, and goal-directed behavior. During these activities, the participants were instructed to stop and look up to see whether a red or green card was held up when a whistle was blown. A red card indicated an immediate change in the rules of the game and a green card meant the current rules remained in force. The high cognitive engagement and high physical exertion group also participated in various warm-up activities intended to place a high demand on EFs. For example, the participants would warm up with a game of “tag” but had to keep in mind differing rules, responses to acoustic cues and rules, and inhibit prepotent movements. The results revealed greater improvements in shifting (cognitive flexibility) among the high physical and high cognitive engagement group members compared to the aerobic physical activity group and the control group. The researchers concluded that improvements to EF were not attributable to improvements in physical fitness levels but proposed the changes were mediated by the mental engagement required in the experimental group. The authors suggested future PA interventions utilize cognitively enriched team games with changing rules to enhance EF in youth participants (Schmidt et al., 2015).

The results from these studies provided support for the positive impact of acute and chronic PA participation on EF performance among youth participants. In addition, some preliminary findings suggested TC and SE during PA positively impacted EF performance. Future research studies are needed to determine which types of PA as well as the duration and level of intensity of the activities have the greatest impact on EF. It was suggested future experimental studies should implement physical activities that have greater cognitive demand, require complex motor movements, and offer opportunities for social interaction to improve EF in youth populations (Crova et al., 2014; Davis et al., 2007, 2011; Schmidt et al., 2015).

Adolescent Populations

Executive function processes continue to develop throughout adolescence (Welsh, 2002). During these developmental years, several structural changes occur in the brain that include a decrease in grey matter and an increase in white matter in the frontal and parietal cortices, resulting in the progressive development of processes linked to EF (Blakemore & Choudhury, 2006). Performance on tasks requiring selective attention, working memory, and response inhibition improves with development, allowing adolescents a greater ability to handle daily tasks such as decision making and problem solving, multitasking, and scheduling when compared to pre-adolescent children (Anderson, Anderson, Northam, Jacobs & Catroppa, 2001; Blakemore & Choudhury, 2006). Although limited research has examined the influence of PA on cognitive function among adolescence populations, such studies are important to examine as the greatest decline in PA participation occurs during the teenage years (Nader, Bradley, Houts, McRitchie, & O'Brien, 2008).

Researchers utilizing cross-sectional study designs have explored the relationship between physical fitness levels and executive functioning among adolescent participants. Stroth and colleagues (2009) conducted a study evaluating EF among 13- and 14-year-old participants in relation to their fitness status by assessing ERPs during performance on the flanker task. Results revealed faster response latencies and lower errors rates among higher fit adolescent participants, indicating better inhibition and working memory among fit adolescents. Results revealed no significant changes to executive control performance following an acute session (20 minutes) of moderate intensity, aerobic PA.

The effect of acute PA sessions on the EF of adolescent populations has also been examined. Hogan and colleagues (2013) found physically fit 13- and 14-year-olds significantly improved EF performance following a 20-minute session of moderate PA when compared to their less fit peers. A recent study by Soga, Shishido and Nagatomi (2015) investigated the impact of two separate moderate-intensity treadmill sessions on EF among adolescent participants between 15 and 16 years of age. One group exercised at 60% of their maximal heart rate while the other group exercised at 70% of their maximal heart rate. Performance on inhibition and working memory tasks was assessed during and after the acute bout of PA. The results revealed inhibition performance was maintained during the acute treadmill session at 60% maximal heart rate while response accuracy on the working memory task decreased on the working memory task in the 70% group. The researchers concluded various PA intensities might selectively affect EFs in adolescent populations and suggested future research should explore the impact of various intensities of PA on EF (Soga et al., 2015). In conclusion, physical fitness levels as observed using cross-sectional research designs and acute PA might selectively influence different aspects of EF among adolescent populations.

Young Adult Populations

Researchers have explored the relationship among physical fitness levels, acute PA interventions, and executive functioning in young adult populations. Themanson and Hillman (2006) found reduced event-related negativity amplitudes and better corrective actions following errors during a flanker task, indicating better top-down attentional control processing among 20-year-old adults with higher levels of cardiorespiratory fitness when compared to less fit peers. The researchers suggested cardiorespiratory fitness levels might be associated with better cognitive processing for young adult populations. The researchers also explored the impact of an acute bout of aerobic activity on inhibition performance but results revealed no significant changes to EF following 30 minutes of treadmill walking among this sample of young adults. Yanagisawa and colleagues (2010) also examined the impact of an acute bout of PA on EF performance among 19- to 24-year-old young adults. Participants completed a cognitive flexibility and inhibition task before and 15-minutes following an acute bout of PA on a cycle ergometer. The intensity of the PA was controlled so each participant exercised at no more than 50% of their maximal heart rate. The acute PA group showed significantly improved performance on the EF task compared to a control group that did not exercise. The researchers suggested chronic PA interventions might have the same impact on executive functioning among similar populations.

Pontifex, Hillman, Fernhall, Thompson, and Valentini (2009) directly compared the influence of an acute bout of aerobic PA to an acute bout of resistance training among young adult participants 20 years of age. Participants completed a working memory task before, immediately after, and 30 minutes after the cessation of a 30-minute acute bout of aerobic or resistance training activity. Results indicated only the aerobic group displayed significantly shorter response latencies immediately after and 30 minutes after the PA. The researchers proposed that perhaps only aerobic PA induced changes to working memory among young adult populations.

Findings from the previously mentioned PA intervention studies provided support for the relationship among higher levels of physical fitness and better executive functioning as well as acute bouts of PA as a means of improving EF in young adult populations. Results from a meta-regression analysis indicated although some study results revealed a positive association between physical fitness levels and cognitive performance among young adults 18 to 55 years of age, overall effect sizes were not significant between fitness levels and EF performance (Salthouse & Davis, 2006). The researchers proposed the inconsistency in study results might be due to the fact that peak cognitive function was reached during young adulthood. Young adults display high levels of executive functioning prior to a PA, thus variability in EF performance following PA participation might not be observed (Salthouse & Davis, 2006). Further research is needed to determine the influence of chronic PA as well as the influence various intensities, durations, and types of activities might have on EF performance for this population.

Older Adult Populations

The majority of studies aimed at examining the impact of PA on EF have been conducted with older adult (over the age of 55 years) populations. It is the goal of researchers to design the most effective PA intervention to slow, prevent, or even reverse age-related cognitive decline for this rapidly growing population (Deary, Whiteman, Starr, Whalley, & Fox, 2004; Hertzog et al., 2008). The average adult brain experiences a significant loss of cortical tissue volume--as much as 15-50% of gray and white matter between the ages of 30 and 90 years. This change is due to a decrease in vascularization, a loss of cerebral blood flow, and a decline in neuronal activity (Bixby et al., 2007). The prefrontal cortex accounts for over half of the total volume loss in the brain (Royall et al., 2004). Thus, cognitive functions associated with this region, which include memory, processing speeds, attention, and EFs, are negatively impacted by these age-related structural changes (Chang, Labban, Gapin, & Etnier, 2012; Raz, 2000; Weinstein et al., 2012).

Results from cross-sectional and experimental study designs have revealed a positive association among physical fitness levels, acute and chronic PA participation, and healthier brain structure among older adult populations (Colcombe et al., 2004, 2006). Findings from cross-sectional designs using neuroimaging and neuroeletrical techniques indicated older adults with higher levels of physical fitness have significantly more gray matter in brain regions including the frontal, temporal, and parietal lobes compared to less fit older adults (Colcombe et al., 2003). Similar studies found significantly more gray and white brain matter volume in the prefrontal cortex (Colcombe et al., 2004; Weinstein et al., 2012) and the hippocampus (Erickson et al., 2009) among higher fit older adults when compared to less fit older adults.

Older adults with higher levels of physical fitness were also found to perform better on inhibition and switching tasks compared to older adults with lower levels of physical fitness. Dai and colleagues (2013) compared switching abilities among older adults who participated in externally-paced physical activities such as table tennis and regular tennis to older adults who engaged in more traditional PA contexts such as jogging or swimming among older adults. During a switching task, participants followed a set of rules to complete one task (e.g., identifying a number as even or odd) and then immediately switched to an alternative set of rules to address another task (e.g., identifying a number as higher or lower than five) to complete the task. This type of task utilized specific dimensions of EF including inhibition and working memory. Previous research found older adults tended to have an increased switch cost, indicating a longer latency period and more errors when having to switch between two tasks with different rules. These observed performance deficits are believed to be associated to age-related declines in working memory and inhibition (Themanson, Hillman, & Curtin, 2006). Results from this study indicated significantly faster response times in both PA groups compared to a control group of sedentary older adults.

Results from a correlational analysis revealed better cognitive flexibility performance among more fit older adults compared to less fit peers (Berryman et al., 2013). Physical fitness levels were assessed using strength, mobility, and cardiovascular fitness tests (VO_2 max) among healthy older adults between 65 and 75 years of age. Covariates were considered and included age, education, muscle mass, and gender. Dupuy et al. (2015) found higher fit older women as assessed with a VO_2 max test performed significantly better on cognitive flexibility and inhibition tasks when compared to lower fit older women. Collectively, results indicated a significant relationship between fitness levels and executive functioning among older adult populations (Berryman, et al., 2013; Dai et al., 2013; Dupuy et al., 2015).

Other researchers provided evidence to support improved cognitive performance following a single acute session of PA among older adults. Kimura, Yasunaga, and Wang (2013) found low intensity PA requiring less than three METs (metabolic equivalent task) positively impacted response time during a task-switching measure compared to exercise requiring more than four METs. Similarly, Wang, Chu, Chu, Chan, and Chang (2013) found higher levels of acute PA intensity (80% of heart rate reserve) reduced performance on an EF task while lower intensity PA groups (30% and 50% of HRR) performed significantly better among older adults. The researchers concluded high intensity PA might require more cognitive attention and metabolic resources. Therefore, due to an individual's limited global attention reserve, poor cognitive performance following PA with higher intensities might be observed.

A meta-analysis of acute PA intervention studies found cognitive performance following a single session of PA improved by a mean effect size of 0.20 regardless of intensity of the activity (Lambourne & Tomporowoski, 2010). These findings were supported by a separate meta-analysis that also found a single session of PA had a small but positive effect (d = 0.18) on EF performance for adults over the age of 60 years

(Chang et al., 2012). Although these findings from cross-sectional and acute PA interventions contributed greatly to the existing body of knowledge, experimental studies are necessary to assess the influence of PA on EFs of older adults. Various types of chronic PA interventions intended to promote changes to EF have been employed including aerobic (walking) and anaerobic (resistance) training, multimodal training, and other types of PA including yoga, water aerobics, and tai-chi.

Chronic Physical Activity Interventions

Researchers have examined chronic PA interventions in older adult samples with findings indicating structural and functional changes to the brain following long-term PA participation. Researchers have designed various PA interventions to examine the influence of various PA intensities and the specific type of activity on changes to EF in an effort to find the most effective PA intervention to improve executive functioning for this population. The various physical activities included aerobic and resistance training separately and combined, stability and balancing activities, and yoga and tai-chi. The types of interventions and the findings are discussed in the following sections.

Aerobic Training

One of the first experimental studies was conducted by Dustman and colleagues (1984) who examined the impact of PA on cognition among adult males between 57 and 62 years of age. Response time, cognitive flexibility, and inhibition were measured following a four-month physical activity intervention. The researchers randomly assigned participants to one of three groups: an aerobic only group, a strength and flexibility group, and a control group. Results revealed significant improvements to response time and inhibition among participants in the aerobic training group when compared to the strength and flexibility group and the control group. Kramer and colleagues (1999) found improvements to inhibition and response time following a six-month walking intervention among sedentary adult men aged 60- to 75-years-old. In a neuroimaging study, Colcombe and colleagues (2006) reported significant increases to gray and white neocortical tissue in adults 60-79 years of age following a six-month aerobic intervention that began at lower PA intensity levels and progressed to moderate levels over the course of the study. Additionally, the researchers found after one year of participation in this walking intervention, atrophy in the hippocampus was reversed and memory function significantly improved (Colcombe et al., 2006).

The idea that lower intensity physical activities such as walking could positively influence cognition for older adults has received support by other research findings. Results from a recent meta-analysis by Scherder and colleagues (2014) of randomized controlled trails indicated aerobic walking interventions for sedentary older adults had a significant positive effect on EFs, specifically inhibition and task switching. It was proposed that by incorporating 30 minutes of walking per day at a moderate intensity, sedentary adults over the age of 65 would likely experience cognitive benefits (Scherder et al., 2014). Overall, aerobic-based low to moderate intensity chronic PA participation was found to enhance both brain structure and performance on tasks requiring EF (Colcombe et al., 2003, 2004; Colcombe & Kramer, 2003; Van Praag, Kempermann, & Gage, 1999). Based on these findings, it is expected simple aerobic PA interventions would suffice to preserve cognition among older adults. However, more recent studies have begun to explore the cognitive benefits provided by other types of chronic physical activities.

Resistance Training

Resistance training, or strength training, might be highly beneficial for older adults. This type of PA increases muscle mass, strength, power, and body composition (Haskell et al., 2007), which helps reduce age-related risk factors associated with diseases such as coronary heart disease, osteoporosis, osteoarthritis, and physical disability and thus improves overall quality of life (Dibble, Addison, & Papa, 2009; Hurley & Roth, 2000). The impact of this type of PA on cognitive function in aging adults has been explored through experimental study designs.

A study by Lachman and colleagues (2006) involved a six-month resistance training intervention using therabands (resistance bands) at low to moderate intensities among older adults diagnosed as having at least one disability. Participants ranged in age from 60 to 94 years and were randomly assigned to an experimental group, which was assigned home-based resistance training activities, or a control group. The PA intervention occurred three times a week and was a videotaped program led by a trained instructor. The resistance levels of the bands increased over the six-month intervention trials for all participants in the experimental group. After controlling for age, education, gender, and level of disability, results revealed changes in resistance level were a significant predictor of working memory. The researchers suggested progressive resistance training might help improve working memory among older adults.

Cassilhas and colleagues (2007) implemented a 24-week resistance-training program to explore the differences in resistance training intensities on EF among older adults. Participants ranged in age from 65-75 years, and were randomly assigned to one of three groups: a moderate-intensity group (50% of their one-repetition max, RM), a high-intensity group (80% of their one-RM), or a control group that did not participate in PA. The two experimental groups participated in 3 one-hour sessions per week for six months. The findings revealed significant improvement in tasks requiring attention among both groups regardless of resistance intensity and significant improvements to working memory performance in both PA groups compared to the control group. No differences were found between the two PA intensity groups. The researchers suggested that regardless of intensity, resistance training might have a positive influence on executive processes for older adults.

Other randomized control trial study designs utilized resistance training in conjunction with balance and stability activities intended to influence cognitive function and serve to prevent falls among older adults. Liu-Ambrose and colleagues (2008) explored the impact of once- or twice-weekly resistance training on the EFs of 155 senior women over a 52-week period. The physical activities included both balance and resistance activities. All three components of EF were assessed before and after the PA intervention. The results indicated improved performance on tasks that required inhibition within both groups regardless of frequency of participation. These researchers proposed resistance training might have a selective influence on core EFs.

Another study explored the impact of a resistance training intervention among adults aged 65- to 75-years-old. Forte and colleagues (2013) randomly assigned participants to a multicomponent training group that included coordinative, balance and agility activities, or a progressive resistance-training program intended to improve muscular strength. The researchers controlled for strength gains made by the participants over the course of the study. Findings indicated significantly improved cognitive flexibility performance following three months of the PA intervention regardless of the type of activity. The authors concluded the strength gains made by the progressive resistance training group indirectly impacted improvements to EF. The multicomponent activities were proposed to have more of a direct effect on EF according to the researchers. The participants in this group were required to remember the names of the physical activities, machine settings, and which muscle groups to use during the activities, which was proposed to have served as an additional cognitive stimulus. It was concluded various types of physical activities might lead to improvements to EF through different pathways (Forte et al., 2013).

Meta-analyses have been conducted to review the impact of resistance training when compared to aerobic based training on changes to cognition among older adult populations. Colcombe and Kramer (2003) suggested PA interventions that combined multiple modalities (aerobic and resistance training) enhanced cognition to a greater extent (ES = 0.59) than PA programs that only included aerobic training (ES = 0.41). Kramer and Erickson (2007) concluded greater change to cognition occurred following moderate-intensity aerobic activity when compared to strength-based activities. Kelley and colleagues (2014) also provided support for PA interventions utilizing both forms of PA, aerobic and resistance training, as results indicated larger effect sizes from interventions using both types of training.

To summarize, results from these experimental studies suggested resistance-training interventions when compared to other types of PA such as flexibility, toning, relaxation, calisthenics, and endurance-based training, were beneficial for improving EFs (Chang et al., 2012). Furthermore, the cognitive benefits of resistance training have been sustained for as long as one year following the cessation of the PA intervention in older adults (Davis et al., 2010). These diverse findings might indicate the selective effects aerobic training and resistance training have on EF among older adult populations.

Additional Physical Activity Interventions

Other experimental studies have explored the impact of additional types of PA interventions on changes to EF among older adult populations. Liu-Ambrose and colleagues (2008) employed a home-based PA intervention that included both balance and resistance training activities and results indicated significantly improved inhibition among adults 70 years and older. Gothe and colleagues (2014) found an eight-week intervention using Hatha yoga significantly improved working memory, shifting, and cognitive flexibility among older adults. Other researchers utilized tai chi as a PA intervention and results revealed significantly improved working memory, attention, processing speed (Nguyen & Kruse, 2012; Taylor-Piliae et al., 2012), and increased brain volume (Mortimer et al., 2012) compared to non-exercise control groups. Taylor-Piliae and colleagues (2010) conducted follow-up assessments and found improvements to EF were maintained 12 months after the cessation of the tai-chi intervention.

Regardless of the type of PA utilized, results from experimental studies indicated PA improved mobility and physical fitness levels (Colcombe et al., 2004; Erickson et al., 2011), enhanced EF (Cassilhas et al., 2007; Colcombe et al., 2004; Kramer et al., 1999; Lautenschlager et al., 2008; Liu-Ambrose et al., 2010), and even altered brain morphology (Colcombe et al., 2004; Erickson et al., 2011; Liu-Ambrose et al., 2010, 2012; Voss et al., 2010) in older adults. In conclusion, PA interventions have been found to have a positive influence on EF among adults over the age of 55 but future researchers should carefully consider the type, duration, and intensity of the PA as well as the various dimensions of EF when evaluating changes to cognition for this population.

Explanations of Change in Cognition Following Physical Activity

Despite the findings that indicated PA did not have much effect on cognitive function among adults aged 18-55 years, results from other studies have shown support for PA as a means of enhancing EF among older adult populations. However, researchers have yet to determine *how* and *why* such changes occur. Results from empirically-based studies have indicated various aspects of PA (i.e., intensity, duration, frequency) might influence change in cognition through increased arousal levels that cause metabolic stimulation, resulting in structural and functional changes to the brain (Ploughman, 2008). Recently, researchers have given consideration to other aspects of PA that might influence cognitive changes such as the type of physical activity (resistance versus aerobic training), the complexity of the activity, and opportunities for social interaction during the activity (Tomporowski et al., 2015). Tomporowski and colleagues (2015) suggested the complexity of the activity and opportunities for SE during the activity might cause greater neural stimulation during PA, inducing neuroplasticity and strengthening synaptic transmissions within the brain (Churchill et al., 2002) to a greater extent than variations to PA intensity, duration, or frequency.

Previous research studies were conducted based on a variety of perspectives and hypothesis intended to explain why PA participation induced change to cognitive function. This includes the cardiorespiratory fitness hypothesis, which proposed changes to cognition were a result of improved cardiovascular fitness levels. Other hypotheses indicated PA might impact specific cognitive processes and included the speed hypothesis, the visuospatial hypothesis, the controlled-processing hypothesis, and the executive-control hypothesis. Also included was the concept of exercise-induced arousal, the hypofrontality hypothesis, and the concepts of increased neural stimulation through physical activities that were complex in nature and/or provided opportunities for social interaction.

In Colcombe and Kramer's (2003) meta-analysis, studies utilizing four hypotheses were included, all of which proposed PA selectively impacted different cognitive processes. Researchers suggested PA might only improve performance on tasks that measured low-level central nervous system functions (e.g., simple reaction time) based on the speed hypothesis. Results from previous study designs utilizing the visuospatial hypothesis revealed PA influenced performance on skills requiring participants to transform and remember visual and spatial information. The controlled-processing hypothesis indicated tasks requiring effortful processing initially but eventually becoming automatic with practice and rehearsal were most affected by PA participation. Finally, findings from studies based on the executive-control hypothesis indicated tasks requiring higher-level cognitive processes such as EFs were most influenced by PA participation. The results of the analysis revealed the greatest changes were indicated in EFs following PA interventions. Based on these findings, Colcombe and Kramer suggested EF processes were the most likely to improve following PA participation compared to automatic processes, visuospatial processes, and controlled-processes. Despite the fact that more recent studies have critiqued Colcombe and Kramer's meta-analysis (Hoffman et al., 2008; Smith et al., 2010), improvements observed in EFs following PA have been supported abundantly in research using youth, adolescent, and adult participants (Best, 2010; Chang & Etnier, 2009; Scherder et al., 2014; Verburgh et al., 2013).

The cardiovascular fitness hypothesis has been used to explain improvements to physical fitness levels induced structural changes within the brain. Researchers have suggested these physiological changes mediated the relationship between PA and improved EF performance (Chodzko-Zajko & Moore 1994; Dustman et al., 1984). Initial reasons for supporting the cardiovascular fitness hypothesis were based on the physiological changes that occurred in the brain during and after a single session of PA as well as after long-term PA participation. Physical activity increases oxygen saturation to the brain, a phenomenon known as PA-induced cerebral blood flow. Findings from previous research suggested by directly increasing blood flow to the brain, performance on a variety of cognitive tasks is enhanced (Churchill et al., 2002). Acute PA immediately surges oxygen, glucose, and other nutrients to various brain regions. Prolonged PA was found to induce angiogenesis through the growth of new capillaries from preexisting capillaries, resulting in greater oxygen and nutrient exchange even after the cessation of PA. These physiological responses to PA might be especially important for older adults because as the brain ages, it experiences significant decreases in total capillaries and changes to the vessel walls, causing a loss of oxygen and nutrients to the brain and therefore a deficit in specific cognitive functions, particularly EFs (Churchill et al., 2002).

Experimental research revealed structural changes in the form of angiogenesis occurring in the hippocampus of adult mice following voluntary wheel running (Van Praag, Christie, Sejnowski, & Gage, 1999) and in humans following a PA intervention

(Fabel et al., 2003). The increase in cerebral blood flow following PA also promotes neurogenesis or the growth of new neurons. For neurogenesis to occur, the brain must uptake neurotrophins or proteins that help regulate the growth, survival, and function of neurons, which are an important moderator of synaptic plasticity (Churchill et al., 2002). The plasticity of neurons refers to the efficacy of synaptic transmission and promotes memory retention and the ability to learn novel tasks (Ploughman, 2008). Not only do individual neurotrophins regulate neuronal growth and survival during early years of brain development, they also maintain, restore, and protect neurons during the aging process (Ploughman, 2008). Neurotrophins such as insulin-like growth factor (IGF-I), brain-derived neurotrophic factor (BDNF), and vascular endothelial growth factor (VEGF; Best, 2010; Chang et al., 2012; Kramer & Erickson, 2007) all contribute to angiogenesis (new capillaries) and neurogenesis (new neurons) in specific brain regions, resulting in improved EF (see Gregory, Gill, & Petrella, 2013 for a review). An increase in IGF-I levels was found to be a result of resistance training even after the cessation of the training program (Borst et al., 2001). Increases in BDNF and VEGF have been observed as a result of aerobic training, resulting in hippocampal neurogenesis and improved memory performance (Fabel & Kempermann, 2008; Ploughman, 2008).

Results from cross-sectional research revealed better performance on tasks requiring EF among youth participants with higher levels of cardiovascular (Buck et al., 2008; Crova et al., 2014; Hillman et al., 2005, 2008, 2009; Pontifex et al., 2011). Findings also indicated more efficient attentional resources (Chaddock et al., 2010) and greater cortical matter (Madsen et al., 2010) among higher fit youth participants when compared to participants with lower levels of physical fitness. These findings were similar among younger and older adult populations. Results from cross-sectional studies revealed more efficient brain function during cognitive task performance using ERPs (Dai et al., 2013; Themanson & Hillman, 2006) in addition to more brain volume in physically active older adults when compared to their sedentary or less fit peers (Colcombe et al., 2004; Erickson et al., 2009; Weinstein et al., 2012).

Etnier et al. (2006) conducted a meta-regression analysis to more closely examine the relationship between fitness gains and cognitive performance. The results revealed a significant negative relationship between physical fitness levels and cognitive performance; the researchers suggested future research should focus on other variables that might mediate the relationship between PA and improvements to cognition. Angevaren, Aufdemkampe, Verhaar, Aleman, and Vanhees (2008) conducted a systematic review of studies that utilized randomized controlled trial study designs to implement aerobic-based PA interventions aimed at improving physical fitness levels in adults over the age of 55 years. The outcome variables assessed in each of the studies included changes to attention, memory, perception, speed, motor function, and EFs following the PA interventions. Results from the review indicated improved physical fitness levels as a result of PA participation did not coincide with improvements to cognitive function. The authors suggested further studies were needed to assess the reasons underlying changes to cognitive following PA interventions. Other hypotheses have also been explored to further examine the relationship between PA-induced changes to EFs.

Dietrich (2003) proposed the hypofrontality hypothesis--when two tasks are being performed simultaneously, performance on one task might be compromised if both tasks require high levels of attentional resources to be completed successfully. For example, if a PA is too physically demanding (e.g., high intensity or anaerobic activities such as sprinting), then a decrease in performance on cognitive tasks that require EF might be observed. Similarly, if the PA requires a high level of cognitive demand to perform successfully, such as group game activities, a decline in cognitive performance on tasks that require EFs to complete might occur. For example, Lambourne and Tomporowski (2010) reported participants who cycled performed significantly better on cognitive tasks *during* and *after* the acute PA session, whereas participants who ran on a treadmill only improved cognitive performance *after* the session. Although treadmill running has been recommended as an effective type of PA to enhance EF (Colcombe et al., 2006; Kramer et al., 1999), PA on a treadmill requires more balance and overall body coordination compared to cycling. It was suggested treadmill activities require greater cognitive attention than cycling to perform successfully and therefore caused a detriment to performance on tasks requiring EFs. The researchers proposed future research should consider the cognitive demands of the PA when evaluating changes to EF during and after a PA session (Lambourne & Tomporowski, 2010) as explained by the hypofrontality hypothesis.

To review, inadequate evidence suggested physical fitness improvements alone explained improvements to cognitive function following physical activity participation. Hypotheses that proposed explanations for changes to EF following acute or chronic PA suggests PA might influence specific cognitive processes such as EFs but might not be solely attributed to improvements in physical fitness levels. Other mediators have been explored as potential variables within the PA context that might cause greater neural stimulation, thus producing substantial changes to EFs across all populations. Researchers have suggested physical activities with high levels of TC might positively influence performance on tasks requiring executive functioning. Similarly, researchers have suggested physical activities that offer opportunities for SE might have a positive influence on performance on EF tasks.

Task Complexity

It has recently been proposed physical activities that are more cognitively and motorically complex might play a mediating role in improving EF when compared to simple, repetitive activities. Activities that require movement speed, balance, flexibility, and physical and cognitive adaptability have been found to activate brain regions (prefrontal cortex and the hippocampus) believed to control EFs (Best, 2010; Voelcker-Rehage, Godde, & Staudinger, 2011). Researchers suggested by creating a PA context that has high contextual interference, demands mental control, and offers novel experiences and opportunities for learning, greater improvements to EF might be observed (Best, 2010; Tomporowski et al., 2015).

Results from previous studies with rodents indicated complex physical activities increased cortical thickness (Nithianantharajah & Hannan, 2006), strengthened synaptic neurotransmission (Van Praag, Christie, et al., 1999), and induced angiogenesis (Black, Zelazny, & Greenough, 1991). Ekstrand, Hellsten, and Tingstrom (2008) conducted a study that involved randomly assigning rats to one of three groups: an aerobic-only group (wheel running), a maze-like complex PA group, and a control group without PA. The complex PA environment included various wheels, ladders, and ropes that were changed every two weeks to provide novelty. It was proposed the more complex PA context would cause greater structural changes to the brain when compared with the simpler aerobic activity. Results revealed angiogenesis had occurred in both the hippocampus and prefrontal cortex brain regions of the complex PA group while angiogenesis only occurred in the prefrontal cortex of the aerobic group. The researchers attributed the changes to these brain regions to the cognitive engagement and motor challenge required in the complex PA environment (Ekstrand et al., 2008). McKenzie et al. (2014) created several complex running wheels for adult rodents with irregularly spaced rungs. The researchers proposed the complex wheels would require the mice to adapt an asymmetrical gait, continuously learn novel motor movements, and cognitively adapt to the various wheels to run successfully. Results revealed increased myelination of the neurons, resulting in more efficient neuron communication within the motor cortexes of the rodents who ran on complex wheels compared to rodents who ran on regular running wheels. Findings from these studies provided support for the influence of complex PA environments on brain structure among rodent populations.

Similar findings were reported by researchers who examined complex PA and EF among youth and adolescent samples (Budde et al., 2008; Chang et al., 2013; Crova et al., 2014; Schmidt et al., 2015). Results from a study conducted by Budde and colleagues (2008) revealed significant improvements to EF performance following a 10-minute session of PA. The tasks required the participants dribble a ball with their hands, pass between partners with hands and feet, and pass through targets using multiple types of sports balls (soccer balls, volleyballs, footballs and handballs). To be successful at these tasks, the participants had to use bimanual, coordinative, and complex motor movements. Results revealed significant improvements to EF in the complex PA group when compared to changes in EF following a simple PA intervention. The researchers concluded the complex motor task relied on frontal-dependent cognitive processes and therefore enhanced prefrontal neural functioning, resulting in greater improvements to EF.

Chang and colleagues (2013) initially intended to evaluate how various PA intensities influenced EF among kindergarteners who had been diagnosed with attention deficit hyperactivity disorder. The researchers implemented an eight-week PA program with either low or moderate intensity levels that involved the participants learning soccer-specific skills, which required a high level of motor coordination to be successful at the activities. Results indicated significant improvements to inhibition performance following the eight-week intervention regardless of intensity. The researchers concluded the complex movements of the intervention might have facilitated the cognitive change to a greater extent than the various intensities.

Crova et al. (2014) examined the effects of a traditional PA program to that of an enhanced PA program on EF performance among 9- and 10-year-old participants. The enhanced PA intervention included cognitively and motorically demanding activities with tennis-specific training and externally regulated team games. The researchers assessed performance on a task requiring inhibition and proposed greater improvements to EF would be observed among the participants in the enhanced PA group following six months of the intervention. The researchers accounted for changes in physical fitness and results revealed participants in the enhanced PA group who were classified as overweight improved inhibition performance to a greater extent than their non-overweight peers in the traditional PA group. The authors attributed the improvements in EF to the complex, bimanual activities and note the enhanced PA program promoted greater neural stimulation compared to the traditional PA program.

Schmidt et al. (2015) also created a complex PA environment for 10- and 12-year-olds that promoted both high physical exertion and high cognitive engagement through team game activities. The researchers proposed greater improvements to EF would be observed in the group that participated in the high physical exertion and high cognitive engagement activities compared to a high physical exertion and low cognitive engagement group and a control group that participated in low physical exertion and low cognitively engaging activities. The experimental group participated in team games that included floorball and basketball where the participants had to utilize mental control, coordinative movement, and goal-directed behavior to be successful. This group also experienced random changes to the rules where participants had to look up when a whistle was blown to see if the instructor was holding up a red or a green card. A green card indicated the rules of the game did not change and a red card indicated an immediate change in the rules. Warm-up activities included “tag” games where the participants had to remember various rules, respond to acoustic cues, and inhibit prepotent movements. These complex activities required the participants to utilize EFs to be successful. Results indicated greater improvements in shifting in the team games group compared to the aerobic only and control groups. These findings provided further evidence to support complex physical activities to promote improvements in EF among youth populations.

Dai et al. (2013) examined differences in EF performance among older adult populations between 65 and 75 year of age. The researchers compared performance on tasks requiring EF among individuals who reported more frequent participation in externally-paced, unpredictable PA environments (tennis and table tennis) to individuals who reported more frequent participation in internally-paced, predictable PA environments (jogging and swimming). The EF tasks measured global switching performance, which required working memory to maintain and successfully complete two tasks with differing goals (Kray & Lindenberger, 2000). Results indicated better global switching performance among participants who reported more frequent participation in unpredictable PA environments. The researchers concluded the more complex PA environments utilized working memory to a greater degree than traditional environments and were, therefore, more effective at preserving EF in the sample of older adults.

Forte et al. (2013) designed PA interventions that included a muscular strength group and a multicomponent PA group intended to positively influence executive functioning among adults 65 to 75 years of age. The multicomponent intervention included various physical activities that promoted coordination training, balance, and agility whereas the strength group only focused on improving muscular strength through resistance training with little variation to the physical activities. Results revealed greater improvements to EFs in the multicomponent group when compared to the muscular strength group following twice weekly sessions over a period of three months. The researchers suggested the complexity and coordinative demands of the multicomponent setting had a stronger impact on neuroplasticity, resulting in greater gains in EF. Collectively, these findings indicated cognitive adaptations might be a result of the complex PA context and provided further support for the implementation of complex PA interventions to promote advances to EFs among older adult populations.

When considering the improvements to cognition following PA interventions among youth populations, it is important to note that many of the PA interventions designed to enhance cognition utilized group game activities. Participation in group games requires motor coordination and the participant must anticipate the behavior of teammates and opponents, which places a high demand on EFs (Crova et al., 2014; Schmidt et al., 2015). Furthermore, group games require social interaction between participants in order to cooperate, communicate, and problem solve to be successful at the activities. It has been suggested social exchanges during PA might induce neuroplasticity to a greater extent than physical activities done alone (Best, 2010; Crova et al., 2014; Holt & Sehn, 2008). The level of social engagement (SE) that occurs within various PA contexts has been proposed as a potential variable mediating the relationship between PA and changes to EFs.

Social Engagement

Results from studies among rodents revealed increased neurogenesis in the hippocampus of adult rats who ran on wheels in conjunction with group housing when compared to rats who ran on wheels but lived in individual housing (Stranahan, Khalil, & Gould, 2006). Although both rodent groups had an increase in corticosterone levels following the running sessions, the individual running group had significantly higher levels of the hormone. The researchers suggested the social housing setting might have prevented the stress hormone from reaching detrimental levels following the PA. Although these findings indicated the importance of social networks outside of the PA contexts, results from studies using human participants indicated a high level of SE during PA might be an effective form of neural stimulation that improves EF among human populations (Tomporowski et al., 2015).

It is important to first explain the degree to which SE might occur during PA or, in some cases, is even required within various PA contexts. As described by Landers and Lueschen (1974), cohesion among sport teams is defined by the nature of interactions among teammates. The level of interaction among teammates can be assessed on a continuum from coactive to interactive. Coactive sports settings are defined as activities where team interaction and coordination is not necessary to achieve the goals of the sport (i.e., bowling, golf). Interactive sport contexts are defined as activities where team members are required to work together and coordinate their action plans to achieve the goal of the sport (i.e., soccer, basketball). During PA interventions that involve group games, the degree of SE would be considered more interactive due to the collaborative nature of the activity. These PA contexts involve a greater degree of SE through the cooperation, strategizing, problem solving, and communicating required by the participants to be successful. Such physical activities might include games such as tag, basketball, pickle ball, or tandem bicycle riding. Physical activities that involve a level of SE that is more *coactive* might include golf, group fitness classes, or hiking with a partner.

Pesce et al. (2009) compared the effect of an individualized circuit training group and an aerobic games group on the EF performance among 11- to 12-year-old participants. Results indicated improved memory recall in the aerobic game participants when compared to the individual circuit training participants. The researchers concluded the group game setting provided opportunities for SE during the activity, which might have positively impacted memory performance. Crova et al. (2014) also provided support for higher levels of SE positively influencing EF among youth participants. The results from this study revealed significantly improved performance on EF tasks among the enhanced PA group. The researchers noted the enhanced intervention provided participants more time to spend with their peers during the activities when compared to the traditional PA group. These researchers also noted the high level of SE should be considered as a potential mediating variable influencing the improved inhibition for this sample of youth participants.

Results from empirical studies with older adults also provided support for the positive impact of SE during PA on executive functioning. Dai and colleagues (2013) suggested participants who engaged in tennis and table tennis activities more frequently were exposed to more SE opportunities than those running on treadmills or swimming. The researcher proposed the group component of tennis and table tennis might have been a possible mediator for PA and the superior global switching performance for the sample of participants.

Mortimer et al. (2012) compared pre- and post-EF performance among adults between 60 and 79 years of age. Participants were randomly assigned to one of four groups: a social interaction group, a PA intervention group that involved tai-chi, another PA intervention group that involved walking, or a control group for 21 weeks. Participants assigned to the social interaction group met with two other individuals at a neighborhood community center for one hour three times a week to discuss topics chosen by the participant. The tai-chi group met with two other people to practice tai-chi three times a week and sessions lasted approximately 50 minutes. The walking group met with two other people three times a week at a park and were instructed to walk quickly around a 400-meter track for approximately 50 minutes. Results indicated significantly improved performance on tasks that required EF among the social interaction group and even greater improvements among the tai-chi group. Results from a neuroimaging measure indicated both the tai-chi and social interaction groups had significantly more brain volume following the intervention when compared to the group involved in daily 30-minute walking sessions and a control group. The researchers concluded the tai-chi activity was a form of moving meditation and required sustained attention by the participants, resulting in more brain volume and performance on cognitive tasks. The researchers also proposed the neural stimulation that occurred during the social interaction group meetings had led to increases in brain volume and improvements to tasks requiring executive functioning among this group of older adults.

It was proposed the neurocognitive benefits of social physical activities are of particular importance to older adult populations. Research results indicated social isolation was linked to accelerated cognitive decline (Berkman, Glass, Brissette, & Seeman, 2000). Older adults with low quality or smaller quantities of social networks are at a greater risk for social isolation and are at a greater risk of all-cause mortality compared to adults with greater ties to friends, family, and the community (Bowling & Grundy, 2009). Seeman et al. (2001) reported a strong, positive association between high levels of EF and social contact among older adults after controlling for other lifestyle factors such as PA participation, socioeconomic status, and physical health. Results from another study indicated larger social networks and more frequent SE were associated with a slower rate of cognitive decline and better cognition, particularly EFs, among older adults (Barnes et al., 2004). Therefore, PA environments that provide more opportunity for SE might improve EF to a greater extent than physical activities done alone among older adult populations.

Summary

Findings from previous research provided support for PA interventions as a means of enhancing EF across a lifespan. However, researchers are still uncertain as to how PA influences cognition. Several theoretical foundations and hypotheses have been proposed to explain the relationship between PA and improvements to cognitive performance. Some research results indicated PA only impacts specific cognitive processes such as EF while results from other studies attributed improvements to EF to changes in physical fitness levels that might occur as a result of PA participation. Researchers also explained changes to cognition with regard to PA variables such as level of intensity, frequency, or duration of the activity. Other variables considered included the complexity of the activity and the amount of SE that occurred during the activity. In addition, researchers who examined changes to brain structure and function among rodent and youth populations established initial support for the possible influence TC and SE have on cognition, citing the enhanced neural stimulation that occurred during complex activities and through the level of SE that occurred during the activity. As previously reviewed, researchers are beginning to discuss the influence TC and SE have on executive functioning among older adult populations; however, additional research is needed to directly analyze the impact both variables might have on changes to EF in an effort to find the most effective PA context to promote cognitive function for this growing population.

CHAPTER III

METHODOLOGY

Three research questions guided the current study. The first research question explored the contribution of the cognitive and motoric complexity of PA to variability in EF performance among physically active older adults. The second research question examined the relationship between the level of SE during PA and the variability of EF performance in older adults. The third research question examined the influence of both highly sociable and highly complex physical activities on executive functioning in older adults. Results from previous research suggested these two PA characteristics might mediate the relationship between PA and cognitive improvement in rodents (Ekstrand et al., 2008; Stranahan et al., 2006) as well as in youth and adolescent populations (Crova et al., 2014; Pesce et al., 2009) and older adults (e.g., Dai et al., 2013; Mortimer et al., 2012; Tomporowski et al., 2015). It was anticipated older adults who participated more frequently in more complex physical activities would exhibit better performance on cognitive tasks specifically evaluating EFs when compared with older adults who more frequently participated in simple physical activities. Similarly, it was expected older adults who participated more frequently in socially engaging physical activities would perform better on tasks requiring EFs when compared with older adults who frequently participated in physical activities that occurred in individualized contexts.

Research Design

A cross sectional, non-experimental research design was used in the current study. Cross-sectional designs are used to determine whether relationships exist among two or more variables at one point in time (Anderman & Anderman, 1999). This study examined whether levels of TC or SE during various PA contexts explained variability in EF performance after controlling for lifestyle characteristics of the participants. Additional control variables included gender, age, level of education completed, additional number of household members, and current level of physical fitness.

Participants

The sample of participants for this study were males (*n* = 30; 40.0%) and females (*n* = 45; 60.0%) between 60 and 73 years of age (*Mage* = 64.43 years, *SD* = 3.60). Participants (*N* = 75) were predominantly Caucasian (*n* = 74; 98.7%). The average of years of completed education for this sample was 17.08 (*SD* = 2.64 years) and the majority of participants were currently living with one or more additional household members (76.0%; *SD* = .32) at the time of data collection. Participants perceived their own health to be *Very good* on a 5-point Likert scale where 1 = *Poor* and 5 = *Excellent* (DeSalvo, Bloser, Reynolds, He, & Muntner, 2006). Participants reported an average total of 312.28 minutes (*SD* = 241.10) of PA per week and had been engaging in PA on a regular basis for a reported average of 32.95 years (*SD* = 18.92). The average score on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was 29 (*SD* = 1.22) out of 30 possible points. Regarding physical fitness levels, females had an average heart rate of 99.16 (*SD* = 19.40) beats per minute following the Young Men's Christian Association (YMCA; 2000) step test while males had an average heart rate of

89.28 (*SD* = 20.75) beats per minute following the YMCA step test. A complete description of participants' gender, age, race/ethnicity, completed years of education, perceived health, additional number of household members, MMSE scores, and physical fitness outcomes are provided in Table 1.

Table 1

Descriptive Statistics for Participants

	SD	*M*	*N*	%
Gender				
Female			45	60
Male			30	40
Age	3.6	64.43		
60			8	10.7
61			5	6.7
62			6	8.0
63			6	8.0
64			8	10.7
65			7	9.3
66			6	8.0
67			2	2.7
68			7	9.3
69			11	14.7
70			5	6.7
71			1	1.3
73			3	4.0
Race/Ethnicity				
Native American			1	1.3
Caucasian			74	98.7
Complete Years of Education	17.08	2.65		
12			5	6.7
13			1	1.3
14			4	5.3
15			1	1.3
16			30	40.0
17			6	8.0
18			11	14.7
19			2	2.7
20			5	6.7
21			2	2.7
22			7	9.3
23			1	1.3
Perceived Health	4	.80		
Fair			2	2.7
Good			12	16.0
Very Good			32	42.7
Excellent			29	38.7

Table 1 continued

	M	*SD*	*N*	%
Additional Number of Household Members	2	.57		
1			10	13.3
2			57	76.0
3			6	8.0
4			2	2.7
Mini-Mental State Examination	28.85	1.22		
25			3	4.0
26			1	1.3
27			6	8.0
28			7	9.3
29			35	46.7
30			23	30.7

Measures

An interview procedure was used to assess each participant's average seven-day recall of typical PA. The interview questions specifically inquired as to where the activities occurred (i.e., home, fitness center) and the specific type of PA (i.e., resistance training, fitness class, aerobic training). Cognitive functioning was measured through tasks requiring the use of three EF components: working memory, cognitive flexibility/shifting, inhibition, as well as response latency. Other demographic variables assessed included participant age and gender, current level of physical fitness, years of education completed, perceived health, and current number of additional household members.

Demographics. Participants were asked to complete a short demographic survey that included questions about their age, race/ethnicity, gender, and number of years of education completed. The complete demographic questionnaire can be found in Appendix A. Previous research findings indicated education levels were associated with performance on tasks requiring EF (Carlson et al., 2008). Thus, years of completed education was considered during the data analysis. Participants were also asked to provide the number of people who currently lived with them in their residence where 0 = living alone, 1 = living with one other person such as a spouse or child, 2 = living with two other household members and so on. Social isolation was found to accelerate cognitive decline in aging adults (Berkman et al., 2000) and previous study results revealed a strong, positive association between social contact and EF performance among older adults after controlling for other lifestyle characteristics (e.g., fitness levels, socioeconomic status, etc.; Seeman et al., 2001). Therefore, SE based on the participant's living situation was also considered during the data analysis.

The General Self-Rated Health (GSRH) one-item questionnaire is a subjective general health measure that prompts the participant to rate their own perceived health: "In general, how would you rate your health?" Participants responded on a Likert-type scale ranging from 1 = *Poor*, 2 = *Fair*, 3 = *Good*, 4 = *Very Good*, and 5 = *Excellent*. This questionnaire was found to have good predictive validity of mortality across both male and female participants (DeSalvo et al., 2006).

The participants' exercise histories were also considered by asking three specific questions on the demographic survey: (a) "How many years, months, days, have you been exercising regularly?" (b) "How often do you exercise? (days per week)?" and (c) "How many minutes do you exercise in one week (total minutes)?" For the purpose of these three questions, PA was explained to participants as any bodily movement that resulted in energy expenditure and encompassed both exercise and sport activities (Caspersen et al., 1985).

Mini-Mental State Examination. Recent studies exploring the relationship between exercise and cognition in older adults have utilized the MMSE (Folstein et al., 1975) to confirm participants were cognitively healthy and excluded individuals from continued participation when they scored a 23 or lower. Previous researchers were then able to explain their findings from exercise interventions in terms of a cognitively healthy population of older adults (Bolandzadeh et al., 2015; Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012). The MMSE (see Appendix B) was utilized to detect any cognitive impairment present in the participants prior to initiating the testing as the intention of the study was to assess a population of older adults with no cognitive impairment. The MMSE typically requires 10 minutes to complete and the items include the assessment of orientation, registration, recall, calculation and attention, naming, repetition, comprehension, reading, writing and drawing. The administrator was required to praise success and ignore failures so as to avoid emotional reactions that might compromise performance (Cockrell & Folstein, 2002). Results from the MMSE were interpreted as follows: a final score of 24-30 indicated no cognitive impairment, a score of 20-24 might suggest mild dementia, a score of 13-19 might suggest moderate dementia, and a score of less than 12 might indicate severe dementia (Alzheimer's Association, 2016). In populations between the ages of 18 and 69, the average score was 22-25, populations over the age of 70 years had an average score of 21-22, while those 65 years of age showed a mean score of 27 (*SD* = 1.7; Folstein et al., 1975). Participants in the present study averaged a score of 29 out of 30 points (*SD* = 1.22) on the MMSE. None of the participants were excused from the remainder of the data collection based on their MMSE final scores.

Physical activity recall. Participants were interviewed to recall the specific type and frequency of PA participation over a typical week. The interview script involved the researcher asking the participant to "Please walk me through a typical week of PA, starting with a Monday, through the following Sunday. What type of PA do you currently participate in?" Follow-up prompts were then used to clarify frequency and location of the activity to further understand the recalled PA context by the participant. Further prompts were used to make sure all physical activities were accounted for such as gardening or yardwork or daily walks. A seven-day recall to assess weekly PA based on intensity, frequency, and duration was previously utilized to assess typical PA participation in various populations (Nichols, Omizo, Peterson, & Nelson, 1993; Richardson, Ainsworth, Jacobs & Leon, 2001).

Social engagement. Operational definitions and a set of criteria were uniquely and separately applied to establish the level of SE (see Appendix C) and TC of the various types of physical activities recalled by the participants. The degree of SE was defined as the extent to which SE occurred during an activity or was required to be successful at the activity. Low levels of SE occurred when the participant reported performing an activity alone while higher levels of SE occurred during performing the activity in a fitness center or participating in a group fitness class. Social engagement was scored on a 1-5 scale: 1--no SE where the activity was being performed alone and no social interaction occurred while engaging in the activity; 2--limited SE where SE occurred due to the context but was not necessarily required during the activity; 3--some SE might have occurred while engaging in the activity; 4--frequent SE (coactive) where the context offered frequent SE but performing the activity was not dependent on the SE;

and 5--constant social engagement (interactive) where social interactions while engaged in the activity were required to be successful. For example, crossfit was a PA reported by several of the participants and based on the average score of the raters, the final score for SE was a 2-- limited social engagement while playing pickle ball was rated a 5--constant social engagement, interactive.

Task complexity. For the purpose of this study, the level of task complexity for a PA was operationally defined as the degree to which complex motor movements and/or high cognitive demand were required (see Appendix D). To determine the degree of complexity of the types of activities recalled, the raters were provided Gentile's taxonomy of motor skills (Magill, 2011) as well as an additional rating based on anticipation and/or reaction to other people. The raters were asked to answer "yes" or "no" to each of the following characteristics: body stability and body transport, object manipulation, intertrial variability, the environmental context, and reaction or anticipation to other people. During the activity, if body transport occurred, the raters were instructed to reply with a 2; whereas if body stability occurred during the activity, the rater would reply with a 1. If an object was being manipulated during the activity, the raters would reply with a 1 for "no" or a 2 for "yes." If there was no variability between trials while performing the activity, the raters were asked to reply with a 1; whereas if intertrial variability occurred during the activity, the raters were asked to reply with a 2. The environmental context referred to the environment influencing the movements of the performer during the activity. If the environmental context was in motion and the performer had to adjust his or her movements to conform to the environment, the raters were instructed to assign that activity a 2. If the environmental context was stationary and the performer did not have to adjust his or her movements to conform to the environment, the raters were instructed to assign the activity a 1. Lastly, if the activity required the participant to anticipate or react to other people's movements, the raters were instructed to reply with a 2 for the PA. If the participant did not have to react or anticipate the movements of others, the raters were instructed to assign the activity a 1. These scores were then averaged for a final TC score for each PA reported by the participants. The less complex activity was closer to a 1 while a more complex activity was closer to a 2. For example, participation in crossfit was assigned a final TC score of 1.8 while playing pickle ball was rated a 2.0.

Evaluating physical activities. Convenience sampling was used to recruit individuals (*N* = 6) who had completed a doctorate and current doctoral students in sport and exercise science to rate the level of social engagement and complexity of various types of PA reported by the participants. All raters were given the opportunity to ask the researcher clarifying or follow-up questions regarding the activities reported or provide comments justifying their ratings. The individuals rated the various activities and the final scores from each rater were averaged so each type of PA was assigned a separate and final score for the levels of TC and SE. A complete list of physical activities and the rater's spreadsheet are provided in Appendix E.

Interrater reliability. To assess reliability and consistency among raters, an intraclass correlation coefficient was computed for the sample of raters (*N* = 6) for both SE and TC. Results revealed acceptable levels of correlation among the raters for SE (.962) and for the TC ratings (.868). These findings allowed for assessment of the variance in the mean among raters' evaluations for both TC and SE on each physical activity recalled (McGraw & Wong, 1996).

Evaluation of the level of social engagement and task complexity. Based on participants' reported seven-day average exercise recall, each type of PA was given a final score based on the individual raters. To account for frequency, the participants' mode or the type of PA most frequently engaged in during a typical week was assessed for each participant. The participant was then assigned final SE and TC scores. Following that step, overall SE and TC scores were averaged and the standard deviation was determined in order to calculate individual z-scores, or standard scores, for each participant. Calculating z-scores where ($z = \frac{(x-\mu)}{\sigma}$) allowed for the SE and TC scores to be combined to create a new variable for each participant: the interactive effect of SE and TC. The z-scores allowed the two variables (SE and TC) to be standardized. It was expected more frequent involvement in socially engaging or more complex physical activities would explain variability in EF performance. It was also anticipated that more frequent involvement in both social engaging and complex physical activities would also explain variability in EF performance among this sample of older adults.

Cognitive Measures

Three cognitive tasks were used to evaluate each of the core components of EF: cognitive flexibility/shifting, inhibition, and working memory (Miyake et al., 2000) in addition to a simple reaction time task to assess response latency. Shifting, also known as cognitive flexibility, was measured using the Trail Making Task: Parts A and B (Gaudino, Geisler, & Squires, 1995). Inhibition was evaluated using a computerized version of the flanker task (Eriksen & Eriksen, 1974) and working memory was assessed using the verbal digit span forward, backward, and sequencing tasks (Weschler, 1981). The Visual Choice Reaction Time computerized task (Li, Coleman, Ransdell, Coleman, & Irwin, 2011) provided a pure measure of central processing speed in milliseconds based on finger responses to a visual stimulus. Previous use of the instruments as well as validity and reliability data for each instrument are discussed below.

Set shifting/cognitive flexibility. Parts A and B of the Trail Making Test (Partington & Leiter, 1949) were used to assess shifting, or cognitive flexibility. The cognitive flexibility component of EF refers to an individual's ability to alternate attention between two tasks with different overall goals (Arbuthnott & Frank, 2000). The Trail Making Test is an efficient and sensitive instrument that reliably discriminates between normal individuals and those with cognitive impairment (Lezak, 1995; Stuss et al., 1989); it has been found to significantly predict values on the Independent Living scale (Loeb, 1996) among adults 63-89 years of age (Bell-McGinty, Podell, Franzen, Baird, & Williams, 2002). Poor performance on both Trail Making Tests might indicate a difficulty in shifting from one mental task to the other (von Hippel et al., 2009) and predict issues with maintaining functional autonomy and independent living, particularly in daily activities (Bell-McGinty et al., 2002). Trail Making Tests A and B are both relatively easy to administer using a paper and pencil; the simplicity, efficiency, and ease of administering make it one of the more commonly used neurocognitive tests (Camara, Nathan, & Puente, 2000). Part A of the Trail Making Test assesses psychomotor speed and requires participants to draw lines on a piece of paper to connect numbers sequentially as fast as they can without lifting the writing utensil off the paper until all 25 numbers are connected. For example, the participant would start with the number one, then connect one to two, two to three, three to four, and so on. If the participant makes an error, the administrator is advised to identify the error immediately and to allow the participant to correct it. Part B of the Trail Making Test immediately follows Part A and requires the participant to draw a line as quickly as possible from one to A, A to two, two to B, B to three, and so on until the task is completed. The time to complete both tasks was evaluated in seconds. Longer times to complete the tasks indicated greater shifting impairment (Gaudino et al., 1995; Lezak, Howieson, Loring, Hannay, & Fischer, 2004). To determine overall set shifting ability, the difference between Tests B and A was calculated where a smaller difference indicated better shifting ability (Liu-Ambrose et al., 2010). A copy of the Trail Making Test: Part A and Part B is provided in Appendix F.

Inhibition. The flanker task (Eriksen & Eriksen, 1974) was used to assess inhibition, which refers to the ability to inhibit inappropriate responses and to resist the interference of distracting stimuli (Miller, 2005). The flanker task is a computerized test that requires participants to identify the orientation of a central arrow cue "flanked" by other arrows congruent or incongruent with the target arrow. Congruent trials occur when the orientation of the flanking arrows is the same as that of the target arrow (→→→→→). Response latencies are typically faster and responses tend to be more accurate during congruent trials. Incongruent trials occur when the orientation of the flanking arrows are in an opposite direction to the central target arrow (→→←→→). Incongruent trials require greater interference control utilizing inhibition than in congruent trials and typically result in longer response latencies and greater error (Eriksen & Schultz, 1979). The average response latencies for incongruent trials were subtracted from the average response latencies for the congruent trials for differences between these times to determine the latency cost for the different trial. Smaller differences implied better inhibitory ability. Similarly, the number of accurate incongruent trials was subtracted from the number of accurate trials for the congruent trials to determine the accuracy costs where smaller differences indicated better inhibition. Age-related cognitive decline was hypothesized to affect the frontal lobe in particular (West, 1996); the interference effect that occurred during the incongruent trials during the flanker task was found to be more pronounced in older adults than younger adults (Zeef, Sonke, Kok, Buiten, & Kenemans, 1996). This cognitive task has been utilized in many previous studies intended to examine an individual's ability to manage interference (irrelevant stimuli) and inhibit a prepotent response (Miyake et al., 2000). Previous research findings not only revealed more difficulty in older adults at ignoring conflicting stimuli compared to younger adults but findings have also shown the ability to ignore conflicting stimuli significantly improved in older adults following six months of aerobic fitness training (Kramer et al., 1999). The flanker task was found to effectively evaluate executive control with and without interference in youth and adolescent samples (Pontifex et al., 2011; Stroth et al., 2009), young adult populations (Themanson & Hillman, 2006), and older adult populations (Kamijo et al., 2011).

Working memory. The verbal digit span forward, backward, and sequential recall tasks were utilized to assess working memory in this sample of older adults (Weschler, 1981). Previous researchers who assessed EF have used this instrument with older adult populations and found it to be a valuable tool to measure working memory (Liu-Ambrose et al., 2010; Voss et al., 2013). During the verbal digit span forward task, the participant is asked to repeat each sequence of numbers exactly as presented whereas the verbal digit span backward task requires the participant to repeat the sequence of numbers in *reverse* order (i.e., 6 – 9 – 4 should be repeated as 4 – 9 – 6). For the digit span sequential task, the test administrator would say a series of numbers and the participant was required to repeat the numbers in sequential order (lowest to highest). For example, 2 – 3 – 1 would be recalled out loud in the following order 1 – 2 – 3 in order for the participant to be successful and to move to the next trial of numbers. The test administrator was advised to read the number sequences aloud at a rate of one number per second and to provide sample trials for both the backward and sequential digit span tasks. Each sequence of numbers began with two digits and increased by one digit each time to as many as eight digits for the backward digit span tasks and as many as nine digits for the forward and sequencing tasks. The testing was promptly stopped when the participant was unable to successfully recollect any two sequences within the same digit length for as many as 14 sequences. For example, if the participant failed to correctly recall the first trial of five digits, the administrator continued on to read the second trial of five digits. If the participant was successful in recalling the next five-digit trial, the task continued to the six-digit trial. However, if the participant failed to recall the second five-digit trial, the task stopped and the next task was administered. The score for each individual digit span task was the number of successful sequences recalled out of 14 possible. The overall score out of 48 possible points was recorded and used as an index of working memory where greater scores indicated better working memory (Liu-Ambrose et al., 2010).

Physical fitness. The participant's cardiorespiratory physical fitness was also assessed. The YMCA step test (2000) provided an assessment of resting heart rate following three minutes of stepping on and off a 12-inch platform at a pace of 96-beats per minute. This test was used to estimate an individual's current aerobic capacity or VO_2max (Santo & Golding, 2003) and demonstrated concurrent validity in estimating cardiorespiratory fitness based on the post-exercise recovery heart beat count (Kasch, 1961). This test was selected because it is relatively easy to administer, can be completed in a relatively short amount of time (approximately five minutes), and is safe for healthy older adults to perform without a medical release (Rikli & Jones, 1999). Participants were allowed to switch their lead foot (i.e., step up with their left foot instead of their right foot) halfway through the three-minute test. At the end of the three minutes, the participants were instructed to sit down and a resting heart rate was assessed for a total of one minute and recorded on the participant's demographic survey. The average resting heart rate following the administration of this test was 99.16 beats per minute (SD = 19.40) for female participants and 89.28 beats per minute (SD = 20.75) for male participants.

Participant handout. All participants were provided a hand-out following the completion of the data collection that included a record of their MMSE final score and the overall average scores for various ages for the overall norm (see Appendix G). Participants' resting heart rate following the YMCA (2000) step test was also recorded along with information on their physical fitness category based on age and gender. Recommendations for PA among adult populations from the American College of Sports Medicine (2016). Finally, brief information regarding factors impacting age-related cognitive decline was also included in the handout. The handout provided the participants with their testing results and served as a token of gratitude for their time and participation.

Procedures

Institutional Review Board

Institutional Review Board (IRB) approval was received to conduct the study from the University of Northern Colorado before the study was initiated (see Appendix H). Data collection occurred at various locations depending on the preference of the participant and included local fitness centers, the University of Northern Colorado campus, a local coffee shop, or the participant's home. The meeting involved an explanation of the purpose of the study and the completion of the informed consent (see Appendix I). The participants were told the purpose of the study was to assess their choice of physical activities throughout a typical week in relation to their cognitive function. The researcher also reassured all participants their responses and cognitive task results would be kept confidential. The researcher followed all standard protocols for the protection of human participants.

Participant Recruitment and Criteria

The participants for this study were adults between the age of 60 and 73 years who participated in regular physical activity. Only participants who scored 24 or higher on the MMSE were included in the study's testing procedures as a final score of 24-30 was indicative of no cognitive impairment (Folstein et al., 1975). To recruit participants, contact was made via phone or email (see Appendix J) with local gym and recreation center owners and managers to gain their permission to recruit willing research participants from their facility. Once permission was granted from the fitness center personnel, flyers (see Appendix K) with drop boxes were set out in communal areas of the gym where members could either take a flyer with information about the study and participant criteria as well as the researcher's contact information or they could complete the back of the flyer and place their contact information in the drop box. Drop boxes were checked once a week by the researcher and participants who had put their information in the drop box were contacted immediately via email or phone to schedule a time where an introduction to the study's purpose, the data collection procedures required, and anticipated time to complete the procedures were discussed. After meeting with participants and completing the data collection, flyers from the fitness centers were offered to the participants to pass out to any friends or family who might also be willing to participate to facilitate an exponential effect (i.e., snowball or domino effect). Another recruiting method involved contacting a local fitness center's manager who emailed out a copy of the recruiting flyer to their members, which resulted in several contacts. Meanwhile, another manager of a different local fitness center handed out flyers to Senior Game athletes during the Senior Olympics in Northern Colorado. Finally, the researcher was granted permission by a local fitness center manager to attend specific group fitness classes at various local fitness centers that targeted older adult populations and recruited from their class. All data were collected between June and August of 2016 in the northern Colorado and western Nebraska regions of the United States.

Sample Size

Sample size decisions were made based on power and effect size considerations (Tabachnick & Fidell, 2013). For the current study, G*Power software 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009) was used to calculate the sample size requirements based on the number of variables in the model. According to Tabachnick and Fidell (2013), the sample size should equal $N \geq 50 + 8m$, where m is the number of independent variables in the study. The current study had five total predictor variables and three tested predictors or main independent variables (TC, SE, and the interactive effect of SE and TC) during PA; thus, the sample size was determined through the selection of a medium effect size (.15) and a power level of 0.80 to reduce the probability of Type II error. The G*Power program revealed an ideal minimum sample size of 68 for the current study. The sample size of 15 exceeded the minimum suggested sample size.

Data Collection

Once contact had been made between the participant and the researcher, a separate one-on-one meeting was scheduled to complete data collection. The meeting took place at a mutually agreed upon time and date in a quiet setting where outside noise did not disrupt the testing procedure. The participant was encouraged to wear clothing appropriate for the completion of the YMCA (2000) three-minute step test. Approximate total time for data collection was between 30 and 45 minutes for each participant. The researcher first explained the purpose of the study and the participant was presented with a consent form to read and sign once concerns had been addressed by the researcher. The MMSE was then completed and scored immediately followed by the demographic survey. The cognitive tasks were then administered in two different orders for every other participant. All participants first completed the computerized simple reaction time task at step two; either Trail Making Tests A and B or the digit span task were administered followed by the computerized flanker task. The final task was whichever task was not complete in step two. Data collection was finalized with the administration of the YMCA step test. Two participants did not complete this portion of the testing; however, the remaining variables for these participants were included in the following analysis.

Data Analysis

Descriptive statistics and inferential analyses were conducted using SPSS 20.0. Descriptive statistics obtained included frequencies, means, standard deviations, variability estimates as well as simple correlations among the variables of interest. The data were assessed for normality and homogeneity using histograms and Q-Q plots in addition to evaluating the data based on the assumptions for the regression analyses. Outliers among the outcome variables were identified using box plots and the upper and lower quartiles (Hoaglin & Iglewicz, 1987) and removed from subsequent analyses. Multicollinearity was assessed for the three predictor variables using correlational analyses with $r \geq .70$ set as the standard for multicollinearity and by examining the tolerance (< .10) and the variance inflation factor (VIF, < 10) from the regression analyses (Myers, 1990). This step was important because if multicollinearity between the predictor variables existed, it would have been difficult to identify the relative contribution of each predictor on the outcome variables.

Previous research findings suggested several of the demographic variables might influence EF in older adults, particularly physical fitness levels (Colcombe et al., 2004), completed years of education (Voos, Callil, Custódio, & Malaquias, 2011), and additional number of household members (Barnes et al., 2004; Seeman et al., 2001). Therefore, independent sample *t*-tests, an ANOVA, and simple linear regressions were utilized based on the categorical, ordinal, or continuous nature of the demographic variables. Findings revealed non-significant relationships among gender, EF outcomes, and response latency. Regression results also revealed a non-significant relationship among age, level of physical fitness, completed years of education, additional household members, and EF outcomes and response latency. Thus, these demographic variables were not included in subsequent multivariate multiple regression analyses. The results from the multivariate multiple-regression analyses were used to examine the relative contribution of TC, SE, and the combination of TC and SC to the three outcome dimensions of EF: working memory, inhibition, cognitive flexibility, as well as response latency. A regression analysis was appropriate to this study because it allowed the researcher to evaluate the unique contributions of the three predictor variables to the dependent variables of interest (Pedhazur, 1997).

Descriptive Statistics

Preliminary data analysis included an examination of the descriptive statistics to identify characteristics of the sample (Huck, 2011). All variables were examined for outliers to assess for skewness and kurtosis and to test the assumption of normalcy. Based on the value of upper and lower quartiles, outliers were identified by assessing the upper third (75th percentile) and lower third (25th percentile) quartiles for each outcome variable. The difference between the two was then calculated and multiplied by 2.2 as this was a more accurate value to assess outlier status based on the smaller sample size used in this study (Hoaglin & Iglewicz, 1987). The resulting value was then added to the upper limit and subtracted from the lower limit; values outside of these bounds were determined to be outliers and eliminated from subsequent analyses. Simple Pearson's *r* correlations were calculated to examine the strength of the relationship between each of the variables of interest in the study.

Main Analysis

Prior to the main analysis, each participant was assigned an overall value based on a multiplicative function of the combined effect of three computed values related to PA involvement: SE, TC, and the interactive effect of SE and TC. Multivariate multiple regression analyses were conducted to determine the variability explained by the three predictor variables and the set of outcome variables that included inhibition, cognitive flexibility, working memory, and response latency. Significance level was established at a Wilks' lambda value of $p = .05$ (Pedhazur, 1997). Changes in the R^2 value and the adjusted R^2 value in relation to the individual contribution of each variable were also examined. The adjusted R^2 accounted for both sample size and number of control variables included in the model and, therefore, was considered a more conservative estimate of the variability explained (Cramer, 1997) in EF performance and response latency. These steps were taken to allow for an assessment of the three predictor variables in the explanation of the variance in the participant's performance on EF tasks and average response latency. The responses from these analyses are provided in Chapter IV.

CHAPTER IV

RESULTS

The primary research questions of this study were intended to examine the influence of various facets of PA on the cognitive function of adults over the age of 60 years. It was anticipated frequent participation in socially engaging PA or PA that had a high level of TC would result in better performance on indices of EFs. Preliminary examinations based on the types of activities reported by the participants involved the assessment of the levels of SE and TC for each activity recalled by the participants.

A cross-sectional research design was employed to examine the relationship between the most frequent types of PA and performance on EF tasks. Demographic variables were also taken into consideration and included gender, age, completed years of education, additional number of household members, and physical fitness levels. The data analysis involved the assessment of descriptive statistics and inferential analyses to explore the relationships among the demographic variables, the three predictor variables (SE, TC and the interactive effect of SE and TC), and the outcome variables (average response latency, response latency during the flanker task, differences in time to complete the TMTs, and the digit span task).

Preliminary Analyses

Preliminary analyses and descriptive statistics in the form of means, standard deviations, and correlations were calculated for the predictor and outcome variables. The sample mean value for SE was 2.76 (*SD* = 1.14) with a range of one to five. For TC, the sample mean value was 1.55 (*SD* = .21) with a range of 1.0 to 2.0. The sample mean for the interactive effect of SE and TC mode was .833 (*SD* = .06) with a range of .06 to 4.19. The average response latency on the simple reaction time task for this sample of older adults was 309.80 milliseconds (*SD* = 59.08) with a range of 224.28 to 521.85 milliseconds. To assess cognitive flexibility, the total time to complete Trail Making Test (TMT): B was subtracted from TMT: A where a smaller difference in the time to complete both tests was indicative of better cognitive flexibility (Liu-Ambrose et al., 2010). The average time between the two tasks for these participants was 35.68 seconds (*SD* = 15.04). Inhibition was assessed with a computerized version of the flanker task (Eriksen & Eriksen, 1974). Each participant received a score for response latency and success rate based on congruent and incongruent trials. The difference between congruent and incongruent trails was calculated for each participant's response latency and success rate. Smaller differences in response time latency and less errors between the two types of trials was indicative of better inhibitory control in older adult populations (Kamijo et al., 2011). The average difference in response latency for this sample of older adults was 33.53 seconds (*SD* = 19.68) and the average difference in correct responses was .68 (*SD* = 1.69) out of a total of 96 trials following 48 practice trials. To examine working memory, the verbal digit span task was administered and included the forward, backward, and sequential digit span tasks. Each participant could earn a possible 16 points for the three tasks, resulting in a total score of 48 points. The average score for the total digit span task for this sample of older adults was 29.24 (*SD* =

4.50) with a range of 16 to 41 points. Table 2 provides the means and standard deviations for all study variables.

The data were examined for normality through histograms, Q-Q plots, and the skewness and kurtosis values associated with each variable. Outliers were identified in relation to the median of each variable based on the upper 75th and lower 25th quartiles (Hoaglin & Iglewicz, 1987) and removed from subsequent analyses. As suggested by Kline (1998), a standard for non-normality might be skew indexes greater than 3.0 and kurtosis values between 8.0 and 20.0. It was also suggested kurtosis values between -2 and +2 could be considered normally distributed data (George & Mallery, 2010). Initially, the histogram for the response latencies had a positive skew, suggesting a violation of normality. Response latency values were then examined for outliers. The values associated with the upper (25th percentile) and lower (75th percentile) quartiles of the median were identified and multiplied by 2.2 to determine the inner and outer fences (Hoaglin, Iglewicz, & Tukey, 1986). Two participants' average response latency values were identified as outside the outer fence (822.365ms and 739.60ms) and removed from the data. Following this step, the new skewness value for response latency was 1.43 and the kurtosis value of 2.40, indicating normality. Normality for the TMTs and flanker response latency was assessed through histograms and Q-Q plots and the skewness and kurtosis values fell in acceptable ranges. Two participants performed the B version of the TMT faster than version A of the TMT, resulting in a final score with a negative value. This outcome resulted in a positively skewed histogram; thus, the two negative values of -9.20 seconds and -7.73 seconds were removed from the data. Additionally, two more values for the difference in TMT: Parts A and B were identified as outliers based on the distance from the upper and lower quartiles and also removed from the data. In assessing normality of this variable based on the differences in the success rate during the flanker task, the histogram and Q-Q- plot suggested non-normality as the kurtosis value was 4.91. The success rate was assessed in the data and the majority of the participants performed congruent and incongruent trials without error, correctly resulting in a 0% difference. Therefore, the success rate during the flanker test was removed from subsequent analysis based on the clear violation of the assumption of normal distribution. Table 2 provides all independent, predictor, and outcome study variables skewness and kurtosis values.

To evaluate the relationships among the three predictor variables (SE, TC, and the interactive effect of SE and TC) and to assess multicollinearity, correlational analyses were conducted. Multicollinearity exists when two or more variables are highly correlated (r = .70 and above) and suggests the different variables might have measured similar constructs. The correlational analysis indicated a significant positive correlation between SE and TC ($r = .67$, $p < .01$), SE and the interactive effect of SE and TC ($r = .42$, $p < .01$), and TC and the interactive effect of SE and TC ($r = .64$, $p < .01$). Although these results suggested multicollinearity might be present, the tolerance and variance inflation factor (VIF) suggested otherwise. It has been proposed that tolerance represents the extent of variability between independent variables where values lower than .10 indicate multicollinearity and a VIF value above 10 indicates multicollinearity (Pallant, 2013). In this case, the tolerance and VIF for SE were .581 and 1.72, suggesting multicollinearity was not present between SE and TC and SE and the interactive effect of SE and TC. The tolerance and VIF for TC was .442 and 2.26, also indicating multicollinearity was not present between TC and SE and TC and the interactive effect of SE and TC. Finally, the tolerance and VIF for the interactive effect of SE and TC were .608 and 1.65, suggesting multicollinearity was not present between the interactive effect of SE and TC and the other two predictor variables. These findings showed independence between the predictor variables and suggested multicollinearity was not present and the assumption was met.

Simple Pearson *r*'s correlations were also calculated to test the strength of the relationship among each of the variables in this study. Significant positive relationships were found between SE and TC, $r = .67$; SE and the interactive effect of SE and TC, $r = .42$; and TC and the interactive effect of SE and TC, $r = .64$, at the $p < .01$ level. The correlation analyses also revealed significant positive relationships between SE and age, $r = .56$, $p < .01$, and between TC and age, $r = .36$, $p < .05$. These findings indicated the older the participants were, the more likely they were to be involved in complex and more socially engaging physical activities. A significant negative relationship was observed between fitness levels and additional number of household members, $r = -.43$, $p < 01$, suggesting higher levels of physical fitness were associated with a greater number of additional household members. Results also revealed a significant negative relationship between the digit span scores and differences in time to complete the TMT, $r = -.30$, $p < .05$, as well as the digit span scores and the differences in flanker response latencies, $r = -.35$, $p < .05$. These findings suggested participants who performed better on the digit span tasks also performed better on the TMT and the flanker task. All results from the correlational analyses can be found in Table 2.

Table 2

Correlations, Means, Standard Deviations, and Skewness and Kurtosis Values for Independent, Predictor, and Dependent Variables

Variable	1	2	3	4	5	6	7	8	9	10	11
1. SE											
2. TC	.67**										
3. Interactive effect of SE and TC	.42**	.64**									
4. Age	.56**	.36*	.28								
5. Fitness Level	-.08	-.23	-.07	.06							
6. Completed Years of Education	.05	.14	.03	-.04	.05						
7. Additional Number of Household Members	-.06	.08	-.15	.03	-.43**	-.16					
8. Average Response Latency	-.08	-.15	-.20	-.18	.16	-.16	.01				
9. Differences in TMT	-.12	.09	.06	-.15	-.23	.06	-.04	-.08			
10. Differences in Flanker Response Latency	.18	.25	-.06	.27	-.02	.16	.02	.02	.10		
11. Digit Span Total	-.10	-.23	-.01	-.01	.23	-.14	-.07	-.05	-.30*	-.35*	
Mean	2.76	1.55	.83	65.43	F99.16	17.08	2.00	309.80	25.68	33.53	29.24
(*SD*)	(1.14)	(.21)	(.85)	(3.6)	(19.40) M89.27 (20.75)	(2.6)	(.57)	(59.10)	(15.04)	(19.67)	(4.50)
Skewness	.32	.62	2.7	.16	.18	.32	.90	1.4	.75	.48	-.14
Kurtosis	-.13	-.67	8.4	-.94	-.20	-.06	3.6	2.4	.16	-.08	.50

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

To assess the relationships among gender, additional number of household members, age, completed years of education, physical fitness levels, and the EF and average response latency outcome variables, inferential analyses were utilized. Independent sample *t*-tests were calculated for the binary categorical data (gender) and the four outcome variables: response latency, difference in time to complete the TMT, differences in response time during the flanker task, and the total digit span score. The *t*-tests were utilized to assess any differences in the outcome variables based on gender. Results revealed a non-significant effect for gender on average response latency, $t(71) = .48$, $p = .74$. Results also indicated a non-significant effect for gender on TMT, $t(69) = -.76$, $p = .63$ or for response latency during the flanker task , $t(71) = -.14$, $p = .90$. No significant effects were observed for gender on the digit span task score, $t(73) = .01$, $p = .79$. These findings indicated no difference in any aspect of EF and average response latency between males and females.

A one-way ANOVA was conducted to compare the effect of additional number of household members on response latency, difference in time to complete the TMT, and differences in response time during the flanker task and the total digit span score. There was a non-significant effect of the additional number of household members on average response latency $F(3, 69) = .12$, $p = .947$, TMT $F(3, 67) = .69$, $p = .56$, response latency during the flanker task $F(3, 69) = 1.68$, $p = .18$, or the digit span task score $F(3, 71) = 1.68$, $p = .18$. The results indicated no significant difference between participants' current number of household members and EF performance and average response latency.

Simple linear regressions were conducted to evaluate the relationships among the remaining continuous demographic variables: age, completed years of education, physical fitness levels, and the four outcome variables. The results of the first simple linear regressions indicated age did not predict a significant amount of the variance in average response latency, $R^2 = .00$, $F(3=1, 71) = .06$, $p = .81$; TMTs $R^2 = .02$, $F(1, 69) = 1.19$, $p = .28$; response latency during the flanker task, $R^2 = .01$, $F(1, 71) = .888$, $p = .349$; or the digit span task score, $R^2 = .00$, $F(1, 73) = .03$, $p = .86$. The results of the next set of simple linear regressions indicated the completed years of education did not predict a significant amount of variance in average response latency, $R^2 = .00$, $F(3=1, 71) = .06$, $p = .81$; TMTs, $R^2 = .02$, $F(1, 69) = 1.19$, $p = .28$; response latency during the flanker task, $R^2 = .01$, $F(1, 71) = .89$, $p = .35$; or the digit span task score, $R^2 = .00$, $F(1, 73) = .03$, $p = .86$. The final simple linear regression revealed the participants' physical fitness levels did not predict variance in average response latency, $R^2 = .01$, $F(1, 71) = .77$, $p = .38$; TMTs, $R^2 = .02$, $F(1, 69) = 1.66$, $p = .20$; response latency during the flanker task, $R^2 = .01$, $F(1, 71) = .95$, $p = .33$; or for the digit span task score, $R^2 = .00$, $F(1, 73) = .04$, $p = .84$. Due to the non-significant relationships, these demographic variables were removed from subsequent multivariate multiple regression analyses.

Main Analyses

Three separate multivariate multiple regression analyses were conducted to answer the three research questions and to assess if the variability in EF performance was explained by SE, TC, and the interactive effect of SE and TC. It was anticipated the individuals who chose to participate more frequently in PA contexts that were socially engaging, complex, or both socially engaging and complex would perform better on tasks requiring EFs. As previously noted, the results from the preliminary analyses revealed non-significant relationships among the demographic variables of gender, additional number of household members, age, completed years of education, and physical fitness levels, and the outcome variables. These analyses were conducted to determine the relationship of the demographic variables to the EF outcomes and average response latency. Should there have been a significant relationship between any of the demographic variables and outcome variables, it would have been necessary to control for the variable in subsequent analyses.

Multivariate multiple regression analyses were conducted to examine the relationships among the predictor variable SE and the outcome variables. The analyses revealed a non-significant relationship among SE and performance on EF tasks and average response latency: Wilks' $\Lambda = .09$, $F(12, 149) = 1.3$, $p = .53$, with R^2 values of .00 for response latency; .04 for the TMT; .01 for the difference in response latency during the flanker task; and .00 for the digit span tasks score. The relationships among the predictor variable TC and the EF and response latency constructs were also non-significant: Wilks' $\Lambda = .12$, $F(32, 189) = .88$, $p = < .86$ with an R^2 value of .01 for response latency; .00 for the TMT; -.00 for the difference in response latency during the flanker task; and .01 for the total digit span task score. These results indicated the SE and TC did not independently explain any significant portion of the variance in EF performance and average response latency. The regression analyses examining the relationship among the interactive effect of SE, TC, and EF performance and average response latency revealed a non-significant relationship: Wilks' $\Lambda = .24$, $F(64, 186) = .92$, $p = .93$ with an R^2 value of .01 for response latency; .00 for the TMT; .00 for the difference in response latency during the flanker task; and .00 for the total digit span tasks. These results indicated the combined variable of the interactive effect of SE and TC did not explain a significant portion of the variance in EF performance and average response latency among this sample of older adults.

The demographic variables were not related to nor did they predict variance in the EF outcomes and average response latency. Therefore, it was not necessary to control for these variables in the main analyses. None of the predictor variables, SE, TC, or the interactive effect of SE and TC explained variability in EF performance or average response latency. These results indicated there were other variables to consider when explaining variability in cognitive function among this sample of older adults.

CHAPTER V

DISCUSSION

The overall purpose of this study was to examine the relationships among socially engaging and complex physical activities and cognitive function in older adults. The various types of physical activities reported by the participants were assigned levels of TC and levels of SE that occurred during the various activities in order to establish a sound method for evaluation of these variables. This study utilized a cross-sectional study design to understand how the levels of TC and SE during PA explained the variability in performance on tasks requiring EFs. Demographic variables including physical fitness level, highest completed level of education, age, gender, and additional number of household members were considered as possible influences on the EF performance among the participants as well.

Physical activity has been identified as having a positive influence on cognitive function, particularly in the later years of life. Participation in PA has been found to reduce the risk of dementia by 28% and the risk of Alzheimer's disease by 45% (Hamer & Chida, 2009). Results from neuroimaging studies revealed structural changes to the brain following chronic PA participation and improvements include increased grey and white matter in the prefrontal and temporal regions (Colcombe et al., 2003; Gordon et al., 2008) and in the hippocampus (Erickson et al., 2009). Physical activity participation was also found to reduce age-related cognitive decline by 38% (Sofi et al., 2011) and to improve performance on cognitive tasks requiring EF among older adult populations (Guiney & Machado, 2013). Executive functions are particularly important for older adult populations as these cognitive processes assist with everyday tasks such as problem solving, planning and scheduling, multi-tasking, and learning novel skills (Bixby et al., 2007; Princiotta et al., 2014). Physical activity interventions designed to maintain and improve these processes are intended to preserve functional autonomy and improve overall quality of life factors for this growing population (Bixby et al., 2007; Hertzog et al., 2008; Karr et al., 2014).

Various types of acute and chronic physical activities promote EF among older adults: aerobic training (see Scherder et al., 2014 for a review), resistance training (see Chang et al., 2012 for a review), tai chi (Mortimer et al., 2012; Nguyen & Kruse, 2012; Taylor-Piliae et al., 2010), yoga (Gothe et al., 2014), and stability activities (Liu-Ambrose et al., 2008). Physical activities that required complex motor movements and effortful, cognitive engagement were found to have a greater influence on EFs than simple and repetitive activities (Dai et al., 2013; Forte et al., 2013). Similarly, socially engaging physical activities might help to improve EF to a greater extent than individualized PA contexts (Dai et al., 2013; Mortimer et al., 2012). Results from studies examining SE and TC in a PA context among children and rodents indicated the positive influence these variables had on structural and function changes to the brain (Castelli et al., 2011; Crova et al., 2014; Pesce et al., 2009; Stranahan et al., 2006). However, these variables have yet to be directly evaluated in relation to PA with older adult populations. Further understanding of the effects of SE and TC within a PA context in relation to executive functioning would assist with designing appropriate PA interventions to most effectively maintain and improve EF for this growing population.

Physical Activity Criteria

Preliminary analyses involved the compilation of various types of physical activities reported by study participants. Specific directions and a set of criteria were provided to individuals working in the field of sport and exercise science to rate the level of SE and level of TC for various types of PA. The individuals were asked to rate each activity for all types of physical activities reported by the participants.

The level of SE was defined as the extent to which the activity required the participant to engage socially with others and was rated based on a 5-point Likert scale where "1" indicated low levels of SE and "5" indicated higher levels of SE. Social engagement was low when the PA was performed alone such as going for a walk or working out at home on an elliptical machine. Medium levels of SE occurred when some social interaction occurred while performing the activity. An example of this mid-level SE activity was cycling with one or more people. Higher levels of SE were identified for activities performed with other people or at a public location. Examples of physical activities considered high in SE included attending a group fitness class at a gym or golfing with other people. The highest level of SE occurred when SE was required of the activity to be successful, e.g., pickle ball or tandem bicycle riding.

The evaluation of TC was assessed based on the following variables: body stability and body transport, object manipulation, intertrial variability, the environmental context, and the extent to which the activity required the participant to anticipate or react to the movements of other people. The evaluators rated the activities with regard to each of the criteria for the variable of TC and their responses were averaged to determine a final TC score for each PA reported by the study participants. A final score closer to "1" indicated lower levels of TC and an example of this type of activity was swimming laps in a pool using the same stroke. A final TC score closer to "2" indicated higher levels of TC associated with the activity. Examples of an activity described as highly complex included kickball, horseback riding, or attending a group fitness circuit training class. Examples of an activity described as low in complexity included cycling on a recumbent bike with no change in the settings or performing resistance training activities without objects.

The scores from each of the six expert coders were averaged so each type of PA reported was assigned an SE and a TC score. Intraclass correlation coefficients were calculated and results indicated reliability among the raters. Each participant was then assigned an SE and TC score based on the PA they reported most frequently engaging in an average seven-day span. The scores for SE and TC as well as the interactive effect of SE and TC were used in subsequent analyses.

It was anticipated the participants who engaged more frequently in physical activities and were rated high in SE would perform better on EF tasks. It was also anticipated the participants who engaged more frequently in physical activities and were rated high in TC would perform better on EF tasks. Additionally, participants who engaged more frequently in tasks and were rated high in SE *and* high in TC would perform better on EF tasks.

Descriptive Statistics

Descriptive analyses were conducted to examine the sample of older adults who participated in the study. The sample was mainly comprised of females (60%), was primarily Caucasian (98.7%), and ranged in age from 60 and 73 years with a mean age of 64.43 years. The majority of the participants (40.0%) had completed a bachelor's degree and perceived their health to be very good (42.7%). All participants scored a 24 or higher out of a possible 30 points on the MMSE and were included in the remainder of the data collection. The average score on the MMSE for this sample of participants was a 29 (*SD* = 1.22). The majority of participants lived with one or more other household members (76.0%) at the time of data collection. With regard to physical fitness levels, female participants had an average heart rate of 99.16 beats per minutes while male participants had an average heart rate of 89.28 beats per minute following the three minute YMCA (2000) step test.

Correlational analyses were conducted for the demographic variables (age, completed years of education, additional number of household and physical fitness levels), the predictor variables (SE, TC, and the interactive effect of SE and TC), and the outcome variables (response latency, TMTs, response latency during the flanker task and the digit span task score) to examine the relationships among all study variables. Simple bivariate correlations indicated a significant ($p < .01$), moderate, positive relationship between SE and TC, $r = .67$; SE and the interactive effect of SE and TC, $r = .42$; and TC and the interactive effect of SE and TC, $r = .64$. The findings indicated participants who participated in physical activities frequently that were high in SE also participated more frequently in physical activities that were high in TC. Although various PA contexts might be high in SE but low in TC, such as walking on a paved trail with one or more other people, oftentimes these characteristics are simultaneously present. For example, the sample of participants reported participation in various types of group fitness classes including Jazzercise, circuit training for seniors, and Zumba. These types of activities were rated high in SE due to the public setting of the class. They were also rated high in task complexity due to the various movement demands and reacting to a live instructor.

The correlational analyses also revealed a moderate, positive relationship between SE and age, $r = .56$, as well as between TC and age, $r = .36$. These findings indicated older participants were more likely to choose to participate in physical activities that were more socially engaging and more complex than were younger participants. Results from the correlational analyses revealed a moderate relationship between physical fitness levels and additional number of household members. This finding indicated higher levels of physical fitness were observed among older adults who lived with one or more additional household members. Significant correlations were also observed between performance on the digit span task and the TMTs as well as between the digit span task and response latency during the flanker task.

Independent sample *t*-tests were used to assess the relationship between gender and performance on the EF tasks as well as on average response latency. Results revealed a non-significant relationship, indicating gender was not an influential factor on EF performance and average response latency. A one-way ANOVA was also conducted to examine the relationship between the number of additional household members and performance on EF tasks and average response latency. These findings also indicated a non-significant difference between groups. The results were not consistent with previous research results that suggested a positive relationship between strong social networks and executive functioning among older adult populations (Seeman et al., 2001). The assessment of additional household members might not have accounted for the level or quality of social networks. A different measurement approach might be necessary to assess the participants' SE.

Regression analyses were conducted to assess the relationships between the predictor variables that included age, completed years of education, and physical fitness levels on each of the four outcome variables (EF performance and average response latency). The results indicated age, completed years of education, and physical fitness levels did not explain a significant amount of the variance in EF performance and average response latency. These findings were not consistent with previous research results that have revealed a positive relationship between physical fitness levels and performance on EF tasks among older adults between 65 and 75 years of age (Berryman et al., 2013) and older women between 55 and 72 years of age (Dupuy et al., 2015). However, previous researchers assessing physical fitness levels utilized a maximal, continuous, graded exercise test (VO_2max test), which might be a more accurate assessment of cardiorespiratory fitness when compared to the three-minute YMCA (2000) step test used in the current study. Physical fitness levels did not explain a significant portion of the variance in EF performance and average response latency for this sample of older adults. The findings regarding age and physical fitness levels were similar to those found in a previous study using a cross-sectional design. Dai and colleagues (2013) reported non-significant differences among age, education level, reaction time, accuracy, and event-related potential indices (P3 amplitude and latency) during a switching task among older adults who participated in regular PA compared to a group of irregular PA participants. Together, these findings suggested there might be more variables contributing to EF performance than completed years of education and the age of the participants in this study.

Main Analyses

Three separate multivariate multiple regression analyses were conducted to address the research questions in this study. It was anticipated that participants who engaged more frequently in physical activities that were high in SE, or high in TC, or high in both SE and TC would perform better on EF tasks. The three predictor variables were included in separate analyses. It was important to assess these variables separately as physical activities might be complex (i.e., circuit training) but not necessarily socially engaging. Other physical activities might be more socially engaging but not as complex, such as walking outside on a paved trail with a partner. Several physical activities reported by the participants that were high in both SE and high in TC included attending a group fitness class or playing doubles tennis. Activities rated low in SE and low in TC included walking on a treadmill or performing body weight resistance training at home alone. It was anticipated participation in a PA that involved both a high level of SE and offered a high level of TC would explain variability in EF among this sample of older adults. Thus, the combined scores for SE and TC made up the third predictor variable.

Physical Activity, Social Engagement, and Executive Function

Findings from the first main analysis that examined the relationship between SE and EF performance revealed frequent participation in socially engaging physical activities did not explain a significant portion of the variance in EF performance among this sample of older adults. These results might be due to criteria established for assessing the level of SE among various physical activities. Additionally, non-significant findings might indicate perceived SE was not taken into account for individual participants. For example, if two participants reported attending a group fitness class, one participant might have attended and been socially engaged through the entire activity. Another participant attending the same group fitness class might have been minimally engaged with others during the PA. The final SE rating for attending a group fitness class was the same regardless of the participant's perception of SE.

The findings from the current study were not consistent with results from a similar study that utilized a cross-sectional research design. Dai and colleagues (2013) found participants who played tennis and table tennis more frequently for PA exhibited better global switching ability, a task that requires working memory and cognitive flexibility, when compared with participants who more frequently walked on a treadmill or swam laps in a pool. The researchers concluded frequent engagement in tennis and table tennis afforded the participants more opportunities to socially interact when compared to older adults who participated in swimming and treadmill more frequently for PA. Findings from the current study were also inconsistent with results from a randomized control trial study designed by Mortimer and colleagues (2012). In their study, three experimental groups engaged in tai-chi, walking, or social interaction over a 40-week intervention period. Findings revealed EF improvement and greater brain volume resulted in the tai chi PA and social interaction groups. The authors attributed the positive changes in EF to the mindfulness of the tai chi activity and the intellectual stimulation afforded to the participants in the social interaction group.

The results from the current study suggested living with one or more individuals might facilitate physical fitness but the SE during physical activities did not explain variability in executive functioning. The results from the current study were not consistent with findings from previous studies with developmental samples where researchers had implemented PA interventions with opportunities for SE to favorably impact EF performance among youth participants. Findings from these studies indicated opportunities to socially interact during PA might have facilitated improved memory recall among 11- and 12-year-olds (Pesce et al., 2013), inhibition performance among 9- and 10-year-olds (Crova et al., 2014), and inhibition and working memory performance among third and fifth grade students (Chen et al., 2014). These studies with youth participants all employed randomized controlled trials to assess changes to EF following interventions designed to provide opportunity for SE for the participants by implementing group games. Older adult populations would perhaps experience similar neurocognitive benefits if similar PA intervention designs were utilized.

Physical Activity, Task Complexity, and Executive Function

In the present study, it was anticipated frequent participation in complex physical activities would explain variability in EF performance in this sample of older adults. Results revealed participation in complex physical activities did not explain variability in EF performance. These findings were not consistent with results from previous research studies that examined changes to brain structure and function following a complex PA intervention (Crova et al., 2014; Schmidt et al., 2015). Older adults would perhaps benefit from PA interventions designed to be cognitively and motorically demanding such as group game contexts or learning novel physical activities.

The results from the current study were inconsistent with findings reported by Dai and colleagues (2013) from a similar cross-sectional research design that assessed variability in EF from participants who engaged in various types of physical activities. The researchers found individuals who participated in tennis and table tennis more frequently performed better on a task requiring working memory when compared to participants who participated in treadmill walking or swimming laps more frequently. The authors described the tennis and table tennis activities as open-skills that were unpredictable, externally-paced, and required spontaneous movement and cognitive adaptability by the participants. Such PA contexts were proposed to induce neuroplasticity to a greater extent than simple, repetitive activities that were not as cognitively demanding (Best, 2010; Tomporowksi et al., 2015). Results from the current study indicated the level of TC did not explain a variability in EF performance.

The current study utilized a different approach to assessing the complexity of various physical activities. Gentile's taxonomy for motor skill classification (Magill, 2011) was used to categorize each activity as high or low complexity based on the variable dimension of body stability or body transport, object manipulation, intertrial variability, and environmental context. An additional variable was included that assessed whether or not the task required the participant to respond or react to the movements of others, e.g., following a group fitness leader or participating in doubles tennis. Future researchers should consider designing PA interventions that directly offer high levels of TC based on previously mentioned variables for older adult populations to observe changes in executive functioning.

Interactive Effect of Social Engagement and Task Complexity on Executive Function

Results indicated the interactive variables of SE and TC did not contribute to variability in executive functioning among this sample of older adults. It was anticipated those who participated in socially engaging and complex physical activities (e.g., attending a group fitness class) more frequently would exhibit better EF performance when compared with individuals who participated in less complex physical activities in individualized settings (e.g., walking outside alone on a paved trail). Directly assessing SE and TC together was an important contribution to the literature. These two variables have been discussed in relation to improvements in EF following PA interventions but to date have not been directly examined or together as a unique variable that potentially influences EF among older adult populations.

Although findings from the current study indicated the interactive effect of SE and TC did not contribute to the variability in EF in this sample of older adults, the interactive effect of these variables should be considered as a form of greater neural stimulation within a PA context. Assessing the impact of these variables together on executive functioning might help design an appropriate and effective PA intervention to promote cognitive function for older adults.

Limitations

Several limitations should be considered in the interpretation of the results from the main analyses of the study. The intention of the preliminary analysis was to identify the levels of SE and TC associated with the types of physical activities recalled by the participants. The level of SE was indicative of how much SE occurred during the activity or was required of the participants to be successful at the activity. Unfortunately, the assessment of SE did not take into account the amount of social interaction that might occur for some individuals in various PA contexts but not others. For example, attending a group fitness class might accompany a high level of SE for one individual and a low level of SE for another individual. Individual perceptions of the level of SE within an activity might have provided greater insight into the degree to which individuals felt socially connected. Observations of social interaction might have also allowed for a more accurate assessment of the level of SE within a PA for the individuals.

Task complexity was assessed using Gentile's taxonomy (Magill, 2011) for classification of motor skills and an additional variable that evaluated the activity based on the reaction or anticipation of other people's movements during the activity, e.g., following a group fitness leader or playing basketball. While this method of identifying the level of TC was a good start to determining more and less complex physical activities, individual perceptions of and previous experience with a PA should be considered when assessing the level of TC associated with different physical activities.

In this study, an interview was used to assess a typical week of PA participation by each participant, which included sport activities, exercise, and other types of physical activities such as gardening or walking. Although this method has been used in various studies to assess PA frequencies, durations, and intensities (Nichols et al., 1993; Richardson et al., 2001), participants often failed to report an accurate portrayal of typical weekly PA. This limitation might be due to social desirability effects--where a participant might over-report positive behaviors such as healthy eating or regular participation in PA (Sallis & Saelens, 2000). A method to counteract this result would be to remove the interviewer from the process and administer a questionnaire (Aquilino & Sciuto, 1990). Other objective assessments to accurately measure PA participation might include observations, the use of technology use (i.e., Fitbit or pedometer), PA journals, or recalling PA participation over a longer period of time than seven days.

Each participant was also assigned a final score for both TC and SE based on the mode or the type of PA most frequently participated in according to their seven-day recall. Although using the PA mode accounted for frequency, it might not be the most valid method to assess participation in complex or socially engaging physical activities. For example, an individual who reported crossfit participation three times a week might have also reported walking with their spouse seven times a week. Because the activity of walking was the most frequent form of PA, the final score for the levels of SE and TC for this participant would not accurately reflect his/her participation in crossfit. Crossfit is considered a highly complex and socially engaging activity compared to walking with a partner, which would be assessed as less complex but just as socially engaging.

It was anticipated physical activities with a high level of SE and/or a high level of TC would contribute to variability in EF and the findings would be generalizable to a wider population of older adults. However, the participants in the current study represented a demographic that was predominantly female, highly educated, and mostly Caucasian. Previous research revealed a significant association between educational level and performance on EF tasks (Carlson et al., 2008). Although the analyses did not show completed years of education explained a significant portion of the variance in EF performance, there was a limited range of educational levels in the sample. Future research would benefit from greater variability in the sample.

Implications for Future Research

Several recommendations for future research are suggested in this section. The first recommendation for future research is to implement a randomized control trial study design to directly assess the effect of PA interventions with high levels of SE, TC, or both on EF performance among older adult participants. The cross-sectional nature of the current study did not allow the researcher to control for these variables within the PA context. In an experiment, the levels of SE and TC could be manipulated and applied to the PA intervention and changes to EF could be evaluated more closely as a result of these variables. Acute PA intervention studies should be initially explored to assess the short-term impact of physical activities that include both high and low levels of SE and TC. Chronic PA interventions that include both high and low level of SE and TC should be employed to assess changes to EF among older adult populations.

The criteria set to examine the level of SE were based on the degree to which participants were required to interact socially with one another to meet the goal of the activity. The location where the activity occurred was considered in the evaluation of SE; however, the perception of SE by the participants themselves was not taken into account. It might be pertinent for future research to more closely assess the level of SE associated with a PA by allowing the participants to rate the level of SE that occurred during their participation. For example, riding bicycles outside with a partner might or may not involve a high level of SE for some individuals while others might rate that activity as highly social. Similarly, the level of TC could also be evaluated through the perception of the participant as experience and individual perspective are certainly factors when considering the complexity of a PA from individual to individual. An individual who has participated in crossfit for an extended period of time is not going to find the activity nearly as complex as someone who has just begun participating in crossfit.

Physical activity participation was measured using an interview procedure, which was intended to obtain an estimate of a typical week of PA for the participant. This method of one-on-one interview could result in self-reporting bias by the participant who might claim more frequent PA participation (Sallis & Saelens, 2000). More objective measures such as the use of technology (accelerometers or pedometers, FitBits), questionnaires, observations, experience sampling method, or a PA journal might provide a direct and accurate assessment of PA participation.

A final implication for future research is to consider assessing changes to EF following various PA interventions in a more heterogeneous sample. The sample in the current study was predominantly female, well-educated, highly fit, and mostly Caucasian. Thus, many other factors such as family upbringing or education could have contributed to the observed EF performance.

Conclusion

The relationships between SE and TC associated in various physical activities and performance on cognitive tasks requiring EF among older adults were examined in the current study. The levels of SE, TC, and the interactive effect of SE and TC did not explain variability in EF performance among older adult participants. Although results from the current study showed SE and TC did not contribute to the variability in EF performance, the assessment of these two variables among various types of physical activities did add to the literature. Further understanding of how these individual variables could be applied to different types of PA contexts might help identify the most effective type of activity to enhance EF for older adult populations.

To date, assessment of the interactive effect of SE and TC has not been directly examined in the research. Qualitative variables associated with PA, SE, and TC have yet to be examined together as having greater neural stimulation for participants than complex or socially engaging physical activities. A PA intervention that fosters *both* SE and TC might promote neural stimulation to a greater extent than these variables alone and should be directly examined in future research studies.

Behavioral interventions that offer social networking or learning a novel skill have been found to improve cognition among older adults (Hertzog et al., 2008). Physical activity contexts that offer both of these variables--social networking and learning a novel skill through complex physical activities such as group games or high levels of contextual interference--might improve cognitive function to a greater extent than simple or individualized PA environments. Physical activity has been found to promote neuroplasticity among older adults, particularly in prefrontal and hippocampus regions of the brain (Park & Gutchess, 2004; Park et al., 2007), and has a positive impact on performance on tasks requiring EF (see Scherder et al., 2014 for a review). Executive functions allow an older adult to successfully perform everyday tasks that require goal-directed behavior such as multitasking, planning and scheduling, or learning a novel skill (Princiotta et al., 2014). Thus, the intention of this research was to determine the most effective PA type to explain variability in EF performance. Physical activity interventions for older adults that involve high levels of SE or TC might help prevent, slow, or even reverse age-related cognitive decline through the preservation of executive functioning. The preservation of these cognitive processes might help adults maintain functional autonomy later in life (Hertzog et al., 2008; Karr et al., 2014). Future well-designed PA interventions have the potential to improve EF to a greater extent by involving complex physical activities and opportunities for social engagement during the activity for older adults.

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APPENDIX A

DEMOGRAPHIC SURVEY

Demographics

Please answer the following questions:

Age: _______

Gender (circle one) M / F

What is your race/ethnicity?

a. Native American
b. Asian
c. African American
d. Pacific Islander
e. White/Caucasian
f. Hispanic
g. Other: ______________________

How many years of education have you completed? _____

Current Number of Members of your Household INCLUDING yourself: ________

Example: 1 = living alone, 2 = living with one other person such as a spouse or child, 3 = living with two other household members, and so on.

In general, how would you rate your health? (circle one)

1 = Poor 2 = Fair 3 = Good 4 = Very Good 5 = Excellent

What is your exercise history?

How many years ____ months _____ days _____ have you been exercising regularly?

How often do you exercise? _______ (days per week)

How many minutes per week do you exercise? ____________

<u>For Testing Administrator</u>:

****Heart Rate – 3 minute YMCA Step Test ___________**

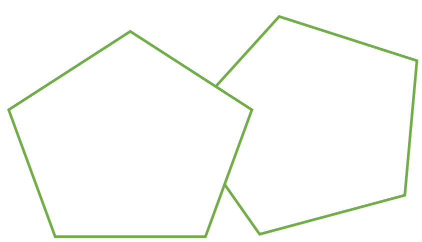
APPENDIX B

MINI MENTAL STATE EXAMINATION

Date ______ Code ______________

Final Score _____________

Questions	**Points**
1. What is the Year? Season? Date? Day? Month?	5
2. Where are we: State? County? Town or City? Present location (home, gym)	5
3. Name three objects (Apple, Penny, Table), taking one second to say each. Then ask the patient to repeat the answers until the patients learns all three.	3
4. Serial 7s. Subtract 7 from 100. Then subtract 7 from that number, etc. Stop after five answers.	5
5. Ask for the names of the three objects learned in question #3.	3
6. Point to a pencil and watch. Have the patient name them as you point.	1
7. Have the patient repeat "No ifs, and, or buts"	3
8. Have the patient follow a three-stage command: "Take the paper in your right hand. Fold the paper in half. Put the paper on the floor"	3
9. Have the patient read and obey the following: "CLOSE YOUR EYES". (Write in large letters).	1
10. Have the patient write a sentence of his or her own choice.	1
11. Have the patient copy the following design (overlapping pentagons).	1



Total Points	**30**

APPENDIX C

SOCIAL ENGAGEMENT CRITERIA FOR EVALUATORS

A) Degree to which social engagement (SE) *occurs during* the physical activity …

1	2	3	4	5
No Social Engagement	**Limited Social Engagement**	**Some Social Engagement**	**Frequent Social Engagement (Coactive)**	**Constant Social Engagement (Interactive)**
Activity is performed alone and no social interaction occurs *while* engaging in the activity.	Due to the context, social engagement may occur but it is not necessarily required during the activity.	Context includes some social engagement *while* doing the activity.	Context offers frequent social engagement but success with the activity is not necessarily dependent on the interaction.	Interacting socially with one (or more) people *while* engaged in the activity and *is required* to be successful.

1 = No social engagement is occurring during exercise

Ex: Walking alone on a treadmill in your basement
Ex: Walking dog outside in evening alone

2 = Limited social engagement may occur during exercise

Ex: Hiking on a trail alone but with other hikers
Ex: Using an elliptical at the gym/fitness center

3 = Some social engagement may occur during exercise

Ex: Group Fitness Class
Ex: Golfing in a group

4 = Frequent social engagement may occur during exercise (Coactive and interactive environment)

Ex: Group Fitness Class where partner work may be required.
Ex: Softball/baseball – both coactive and interactive environment.

5 = Constant social engagement occurring during exercise (Interactive environment)

Ex: Double Tennis
Ex: Pickle ball
Ex: Basketball
Ex: Working out with a trainer

** Defining *coactive* versus *interactive* environments:

Interactive sports require team members to work together and coordinate their actions (i.e., soccer, basketball), whereas **coactive** sport require much less, if any, team interaction and coordination to achieve their goals (i.e., golf, track, bowling) (Lander & Lueschen, 1974).

APPENDIX D

TASK COMPLEXITY CRITERIA FOR EVALUATORS

<u>Instruction for Rating Task Complexity of each Type of Physical Activity</u>

<u>*Consider each of the following variables when rating '*task complexity*' of the activity</u>

<u>Based on Gentile's Taxonomy of Motor Skills</u>

	Body Stability = 1	**Vs.**	**Body Transport = 2**
Example:	*Darts*		*Playing a game of basketball*
	No Object Manipulation = 1	**Vs.**	**Object Manipulation = 2**
Example:	*Weight training using body weight only*		*Weight training using resistance bands*
	Intertrial Variability Absent = 1	**Vs.**	**Intertrial Variability Present = 2**
Example:	*Performing 10 reps on an abdominal crunch machine*		*Golf (not every shot is from the same location)*
	Environmental Context Stationary = 1	**Vs.**	**Environmental Context In Motion = 2**
Example:	*Performing a bench press*		*Returning a tennis serve, skiing*
	Not Anticipation and/or Reaction to Others = 1	**Vs.**	**Anticipation and/or Reaction to Others = 2**
Example:	*Swimming laps in a pool*		*Group Fitness Class following leader*

<u>Questionnaire Instructions</u>: Please fill in each activity type (on spreadsheet) column with a response (1 or 2) for the (5) Task Complexity variables. Do not "over-think" these concepts, go with your first thought on the complexity for the example provided.

---

*<u>Body stability</u> refers to little to no movement of the body during physical activity (archery) whereas <u>body transport</u> refers to movement of the body to perform the physical activity (jogging on a trail).

---

*<u>Object manipulation</u> refers to manipulating one or more objects during the physical activity (lifting free weights) versus <u>no object manipulation</u> which refers to zero objects being manipulated during physical activity (body weight exercises).

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*Intertrial variability present means each attempt is different while performing the activity (golf), versus intertrial variability absent means the activity is performed the same way each attempt, or each trial (shooting a free throw in basketball).

---

*Environmental context in motion refers to the individual having to adjust or conform their movements to the environment (racquetball), whereas environmental context stationary refers to the activity being performed in a stationary environment where the task is self-paced and the movements are internally initiated (elliptical machine)

**Key Question for Environmental Context: does the performer have to regulate/adjust or conform their movements to the environment? If yes – environmental context is in motion. If no – environmental context is stationary.*

---

*Reacting or Anticipation to Others – The cognitive and motor demands of exercise/physical activity and sport activities are higher when the mover must react and/or anticipate and response to others. For example, swimming laps in a pool or walking on a treadmill compared to following a group fitness instructor or playing tennis where the cognitive and motoric demands are much higher due to the anticipation to others.

APPENDIX E

PHYSICAL ACTIVITY SPREADSHEET AND SCORES FOR SOCIAL ENGAGEMENT AND TASK COMPLEXITY

Physical Activity	TC Avg	SE Avg
Sprinting - 25 yards (alone, @ gym)	1.3	2
Cardio Exercise Video (alone, @ Home) - hand weights used - Free Weights (FWs)	1.6	1
CrossFit (individual)	1.8	2
CrossFit (partner or team workouts)	1.9	5
Cycling - Road Bike on Paved Trail (alone)	1.6	2
Cycling - Road Bike on Paved Trail (with one or more other people)	1.7	4
Cycling - Road Bike on Traffic Roads (alone)	1.7	1
Cycling - Road Bike on Traffic Roads (with one or more other people)	1.7	4
Cycling - Recumbent Bike @ Gym (no change in settings)	1.3	2
Cycling - Upright@ Gym (interval program, settings change)	1.5	2
Cycling Upright@ Gym (no change in settings)	1.3	2
Dancing (alone, @ a public location)	1.6	2
Dancing (with partner @ a public location)	1.8	5
Elliptical @ Gym (interval program, settings change)	1.5	2
Elliptical @ Gym (no change in settings)	1.4	2
Elliptical @ Home (interval program, settings change)	1.5	1
Golf (with one or more other people) 18 Holes	1.8	4
Golf (with one or more other people) 9 Holes	1.8	4
Horseback Riding (areana, with one or more other people)	1.8	4
Horseback Riding (trail, with one or more other people)	1.7	4
Jazzercise Group Fitness Class (objects utilized and inclue FW's and resistance bands) - routine changes weekly	1.5	3
Jog outside (alone) on paved trails	1.5	2
Jogging on Track inside @ Gym	1.3	2
Kayaking - Lake (alone)	1.7	2
Kayaking - Lake (with one or more other people)	1.8	4
Kick boxing (group fitness class)	1.8	4
Kickball (game)	2.0	5
Pickle Ball (doubles)	2.0	5
Pilates (@ home alone, video)	1.4	1
Pilates (Group Fitness Class @ Gym)	1.6	4
Piyo Group Fitness Class @ Gym (combination of yoga and pilates)	1.7	4
Racquetball (doubles or triples)	2.0	5
Racquetball (singles)	2.0	5
Resistance Training (RT) - Free Weights at Home (alone)	1.5	1

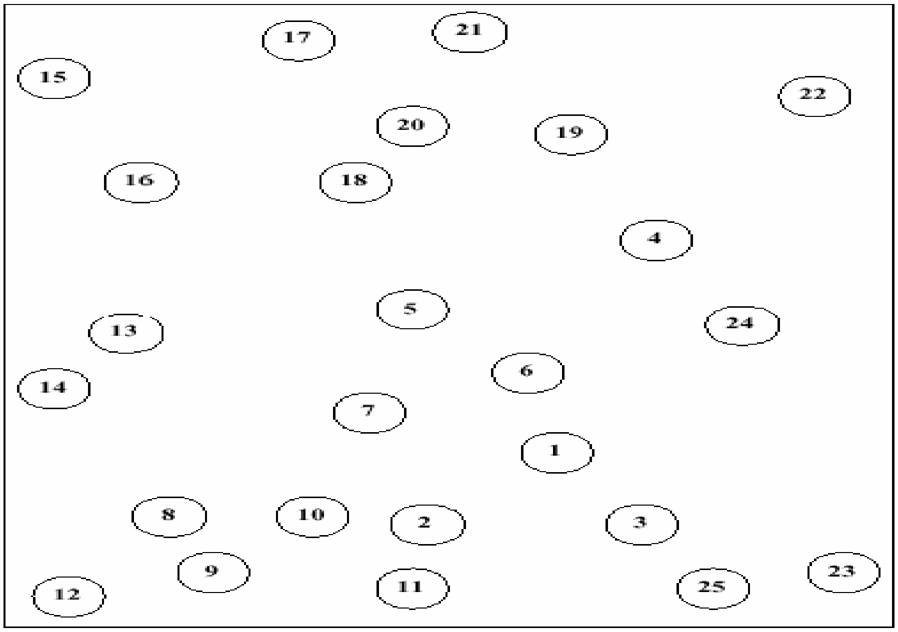
Resistance Training (RT) - Free Weights @ Gym (alone)	**1.5**	**2**
Resistance Training (RT) - Machines @ Gym (alone)	**1.5**	**2**
Resistance Training (RT) - Machines @ Gym (with one more others)	**1.6**	**4**
Resistance Training (RT) - Machines @ Home (alone)	**1.5**	**1**
Resistance Training (RT) - Olympic Lifting @ Gym Alone (squats, dead lifts, snatches, etc.)	**1.5**	**2**
Resistance Training (RT) - Olympic Lifting @ Gym with one more or other people (squats, dead lifts, snatches, etc.)	**1.6**	**4**
Resistance Training (RT) - @ Gym, Alone - Body Weight (push ups, pull ups, planks, etc.)	**1.2**	**2**
Resistance Training (RT) - @ Gym, with one or more other people - Body Weight (push ups, pull ups, planks, etc.)	**1.4**	**4**
Resistance Training - @ Home, Alone - Body Weight (push ups, pull ups, planks, etc.)	**1.2**	**1**
Resistance Training (RT) Body Weight (no objects) - alone @ home	**1.2**	**1**
Resistance Training (RT) Body Weight (with objects such as swiss ball, bosu ball, etc.) - alone @ gym	**1.4**	**2**
Rollerblading (varying paths, paved, alone)	**1.7**	**2**
Rowing Machine @ Gym	**1.4**	**2**
Running in pool @ gym (with one or more other people)	**1.5**	**4**
Senior Ciruit Class (includes cardio, resistance training - machines, FWs, Body Weight RT, Resistance Bands, Medicine Balls, Balance/Stability Exercises and Agility)	**1.9**	**4**
Senior Dance Class (varying dancing)	**1.8**	**5**
Senior Stretching & Bodyweight Strength Training Group Fitness Class @ Gym	**1.7**	**4**
Sit and Be Fit (@ gym, group fitness class - objects used includes: FW's, weighted balls, resistance bands)	**1.8**	**3**
Softball (game)	**2.0**	**5**
Softball (practice)	**2.0**	**5**
Spin - Group Fitness Class @ Gym	**1.8**	**4**

Spin & Circuit Training Class (Group Fitness Class, objects used such as FW's, resistance bands, etc.) @ Gym	**1.9**	**4**
Stair Stepper @ Gym	**1.4**	**2**
Stationary Upright Bike @ Gym	**1.3**	**2**
Stationary Upright Bike @ Home	**1.4**	**1**
Step Aerobics - Group Fitness Class	**1.9**	**4**
Swimming Laps (alone @ gym) changing strokes	**1.5**	**2**
Swimming Laps (alone @ gym) same stroke	**1.4**	**2**
Swimming Laps (alone @ gym) Using equipment (kick board, etc.)	**1.6**	**2**
Swimming in Pool (alone) @ gym, treading water	**1.3**	**2**
Tandum Bike Riding (paved trails, with one other person)	**1.8**	**5**
Teaching Jazzercise Group Fit Class (objects include FW's and resistance bands) - routines change weekly	**1.9**	**5**
Tennis (doubles)	**2.0**	**5**
Trail Hiking (alone)	**1.6**	**2**
Trail Hiking (with one or more people)	**1.7**	**4**
Treadmill @ gym (varying program - speed and incline)	**1.5**	**2**
Treadmill @ home (varying program - speed and incline)	**1.5**	**1**
Treadmill @ gym (settings do not change)	**1.3**	**2**
Treadmill @ home (settings do not change)	**1.3**	**1**
TRX Group Fitness Class (@ gym)	**1.9**	**4**
Upright Bike with moving arms (@ gym)	**1.5**	**2**
Walking outside - alone (same route)	**1.3**	**2**
Walking outside - alone (varying route)	**1.4**	**2**
Walking outside - with one or more other people (same route)	**1.5**	**4**
Walking outside - with one or more other people (varying route)	**1.5**	**4**
Walk Track @ Gym (alone)	**1.2**	**2**
Water Aerobics (Group Fitness Class)	**1.7**	**4**
Yardwork (mowing, gardening, etc.) alone	**1.8**	**1**
Yardwork (mowing, gardening, etc.) with one or more other people	**1.9**	**4**
Yoga @ gym (group fitness class)	**1.7**	**4**
Yoga @ home, alone (video - same video each time)	**1.4**	**1**
Yoga in the Water (@ gym, group fitness class, deep end of pool)	**1.7**	**4**
Zumba (group fitness class)	**1.7**	**4**

APPENDIX F

TRAIL MAKING TEST: PARTS A AND B

TMT – A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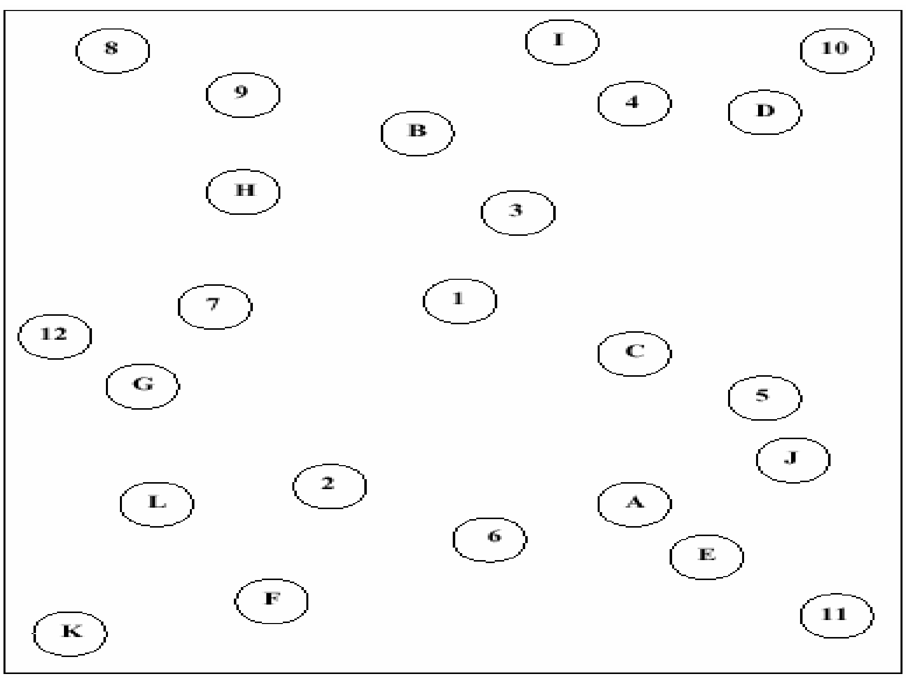
TMT – B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APPENDIX G

PARTICIPANT HANDOUT

UNIVERSITY *of* NORTHERN COLORADO
School of Sport and Exercise Science

Information Packet for Participants: Exercise & Cognitive Health

UNC

Please contact me with any follow-up questions or concerns: Lyndsie Coleman (870)974-2760
Lyndsie.coleman@unco.edu University of Northern Colorado

Exercise Recommendations

According to the American College of Sport Medicine (ACSM), the recommended exercise for adults is:

✓ 150 minutes of moderate-intensity of aerobic exercise per week
- 30-60 minutes of moderate-intensity (5 days/week)
  OR
- 20-60 minutes of vigorous-intensity exercise (3 days/week)

✓ Resistance Training 2-3 Days / Week
- Very light to light intensity (level of weight used) for someone who is older or sedentary.
  - 2-4 sets / 8-10 repetitions to improve strength and power
  - 2-4 sets / 10-15 repetitions to improve strength of middle-age and older adults starting exercise
  - 2-4 sets / 15-20 repetitions to improve muscular endurance

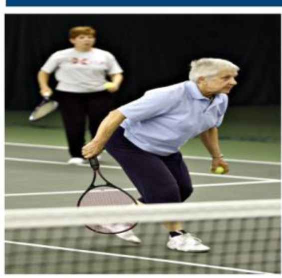
  **Recommend adults wait 48 between resistance training sessions for full recovery

✓ Flexibility Exercise 2-3 Days / Week
- Each stretch should be held for 10-30 seconds to the point of tightness or slight discomfort
- Repeat each stretch 2-4 times, accumulating 60 seconds per stretch
- Stretch only after muscles have been warmed up (light aerobic activity, warm bath, etc.)

✓ Neuromotor Exercise 2-3 Days / Week
- May include balance, agility, coordination and gait exercise training.
  Examples: Tai Chi, Yoga
- 20-30 minutes per day is appropriate for neuromotor exercise

(http://www.acsm.org/about-acsm/media-room/news-releases/2011/08/01/acsm-issues-new-recommendations-on-quantity-and-quality-of-exercise)

Information on the YMCA 3-Minute Step Test



Ratings For Women (age)	18-25	26-35	36:45	46-55	56-65	65+
Excellent	52-81	58-80	51-84	63-91	60-92	70-92
Good	85-93	85-92	89-96	95-101	97-103	96-101
Above Average	96-102	95-101	100-104	104-110	106-111	104-111
Average	104-110	104-110	107-112	113-118	113-118	116-121
Below Average	113-120	113-119	115-120	120-124	119-127	123-126
Poor	122-131	122-129	124-132	126-132	129-135	128-133
Very Poor	135-169	134-171	137-169	137-171	141-174	135-155

Ratings For Men (age)	18-25	26-35	36:45	46-55	56-65	65+
Excellent	50-76	51-76	49-76	56-82	60-77	59-81
Good	79-84	79-85	80-88	87-93	86-94	87-92
Above Average	88-93	88-94	92-88	95-101	97-100	94-102
Average	95-100	96-102	100-105	103-111	103-109	104-110
Below Average	102-107	104-110	108-113	113-119	111-117	114-118
Poor	111-119	114-121	116-124	121-126	119-128	121-126
Very Poor	124-157	126-161	130-163	131-159	131-154	130-151

Your Heart Rate Following the YMCA 3-minute Step Test: ____________

Age-Related Cognitive Decline

Age-Related Cognitive Decline
Dependent on both genetic/heredity *and* lifestyle choices
Lifestyle choices:
- Exercise Participation
- Nutrition
- Social Networks
- Use of tobacco/alcohol/drugs
- Stress
- Medications

Information on the Mini-Mental State Examination

Info for the Mini-Mental State Examination - Intended to test a range of everyday mental skills

✓ Score is out of 30 points
- 20-24 may suggest mild dementia
- 13-20 may suggest moderate dementia
- Score of less than 12 may indicate severe dementia

(http://www.alz.org/alzheimers_disease_steps_to_diagnosis.asp)

✓ Average scores:
Ages 18-69 years: 22-25
70-79 years: 21-22
79+ years: 19-20

Your Score Today on the MMSE ________
If you have concerns, please contact your family physician.

Conclusion

THANK YOU for your participation in our study!
If you would like to see a copy of the results simply let me know and I will make sure you see the final product!

APPENDIX H

INSTITUTIONAL REVIEW BOARD APPROVAL

Institutional Review Board

DATE: May 19, 2016

TO: Lyndsie Coleman

FROM: University of Northern Colorado (UNCO) IRB

PROJECT TITLE: [894433-2] The Influence of Participation in Socially Engaging or Complex Exercise Environments on Executive Function among Older Adults

SUBMISSION TYPE: Amendment/Modification

ACTION: APPROVAL/VERIFICATION OF EXEMPT STATUS

DECISION DATE: May 18, 2016

EXPIRATION DATE: April 21, 2020

Thank you for your submission of Amendment/Modification materials for this project. The University of
Northern Colorado (UNCO) IRB approves this project and verifies its status as EXEMPT according to federal IRB regulations.

We will retain a copy of this correspondence within our records for a duration of 4 years.

If you have any questions, please contact Sherry May at 970-351-1910 or Sherry.May@unco.edu. Please
include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within University of
Northern Colorado (UNCO) IRB's records.

APPENDIX I

CONSENT FORM

Consent Form

PROJECT TITLE: The Influence of Participation in Socially Engaging or Complex Exercise Environments on Executive Function in Older Adults

Researchers: Lyndsie Coleman email: lyndsie.coleman@unco.edu (870)974-2760

Dr. Megan Babkes Stellino email: megan.stellino@unco.edu

Dr. Bob Brustad email: bob.brustad@unco.edu

The purpose of this study is to examine the relationship between physical activity and cognitive (mental) functioning in adults. Participation in this study involves a one-time meeting to complete various questionnaires evaluating demographic information and current cognitive state, as well as paper and pencil and computerized tasks assessing various aspects of cognitive function. The Step Test will also be conducted. The Step Test is a test of physical fitness status and involves three minutes of stepping on and off a 12-inch bench followed by a 60-second heart rate reading. Finally, you will be asked to recall the physical activities that you participate in during an average week. The entire testing process will take approximately 45-60 minutes of your time.

All of your questionnaire responses, heart rate following the physical fitness testing and performance on cognitive tasks will be kept confidential by assigning you an individual code (number). Only the lead investigator and research team will know the names associated with the codes. Data collected and analyzed for this study will be kept in an office in a locked cabinet in the School of Sport and Exercise Science at the University of Northern Colorado and will only be accessible to the researchers. Potential risks in this project are minimal. As with any exercise or physical activity, risks include fatigue, localized muscle soreness, and the potential for strains and sprains of joints of the lower extremities based on the 3-minute Step Test. In addition, if you become too fatigued or uncomfortable, you may choose to stop participating in the fitness testing at any time. In the unlikely event of an injury, we will contact appropriate medical authorities.

Participants will benefit from this study in the following ways. They will be given immediate results of their mini-mental state examination as well as results from their YMCA Step Test. They will also all receive the attached flyer with information on the MMSE, the YMCA Step Test, and current ACSM recommendations for physical activity among older adults. Furthermore, we can discuss lifestyle factors that contribute to age-related cognitive decline. Participants as well as gym/fitness center managers and owners interested in the results will be emailed a report once data is analyzed upon request.

Participation in this study is completely voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact Sherry May, IRB Administrator, Office of Sponsored Programs, 25 Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-1910.

______________________________ ________________________ ___________
Participant Full Name (please print) Participant Signature Date

_____________________________________ ___________

Researcher Signature Date

APPENDIX J

EMAIL TO GYM/FITNESS CENTER MANAGEMENT

Email to Gym/Fitness/Senior Centers

Dear __________,

Greetings! I am a doctoral candidate in the School of Sport & Exercise Science at The University of Northern Colorado and am working on my dissertation research project that seeks to gain a better understanding of the cognitive functioning among active, older adults. I am interested in recruiting adults from your Gym/Fitness Center/Senior Center to participate in my research study.

I would like to offer my services in exchange for recruiting participants from your place of business in the form of one or both of the following:

A) Writing a brief piece for your monthly/weekly newsletter on age-related cognitive decline and the positive impact of physical activity for your clients.

B) Holding a presentation where I can discuss age-related cognitive decline and the positive impact of physical activity with discussion/questions at the end for your clients.

For recruiting purposes, I would like to come by and post flyers around your fitness center (see attached) with a spot for willing participants to sign up for my study. I would also like permission to attend various group fitness or sport activities targeting older adults where I can speak briefly in person to a group of exerciser's (immediately before or after the class per the preference of the instructor) to explain the purpose of the study and recruit willing participants.

Participation in this study is completely voluntary, and all participant responses will remain confidential. Study participation will be completed at a separate time and location with each individual, and will last approximately 45-60 minutes. Procedures include demographics, cognitive tasks and a physical fitness test (3-min Step Test). Participants will be able to see their results immediately. At your request, I would be more than happy to write a brief summary on the findings of the study once all data has been collected and analyzed.

I will be following up this email with a phone call in the next day or two to discuss at your convenience. If you have any concerns about the treatment of the potential research participants, please contact the Sherry May, IRB Administrator, in the Office of Sponsored Programs, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-1910. Please do not hesitate to contact me with any questions, concerns or thoughts of further services I can provide you and your clients, and thank you for your help with this project.

Sincerely,
Lyndsie Coleman, M.S.
(870)974-2760 Lyndsie.Coleman@unco.edu
University of Northern Colorado

APPENDIX K

RECRUITMENT FLYER

UNIVERSITY OF NORTHERN COLORADO

- ✓ Are you 60-70 years of age?
- ✓ Participate in regular exercise and/or sport activities?

If YES: We want YOU to participate in our research study!

Testing Procedures: ~30-45 minutes

- Paper/Pencil & Computerized Cognitive Tasks
- 3-minute Physical Fitness Test (YMCA Step Test)

**Testing can be done at a time & location convenient for you!*

Please contact Lyndsie Coleman

(870) 974-2760 or Lyndsie.coleman@unco.edu

To schedule your meeting today!

UNIVERSITY of NORTHERN COLORADO

School of Sport and Exercise Science